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The Role of Manufacturing in Affecting the Social Dimension of Sustainability

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Submitted by John W. Sutherland

Abstract
Manufacturing affects all three dimensions of sustainability: economy, environment, and society. This paper addresses the last of these dimensions. It explores social impacts identified by national level social indicators, frameworks, and principles. The effects of manufacturing on social performance are framed for different stakeholder groups with associated social needs. Methodology development as well as various challenges for social life cycle assessment (S-LCA) are further examined. Efforts to integrate social and another dimension of sustainability are considered, with attention to globalization challenges, including offshoring and reshoring. The paper concludes with a summary of key takeaways and promising directions for future work.

Keywords
Lifecycle, Human aspect, Social sustainability

1. Introduction

Historically, decision-makers within the manufacturing enterprise have focused on technological and economic issues. Product engineers, for example, often use finite element, computational fluid dynamics, and heat transfer models (software technology) as part of the design process to develop new technologies. Manufacturing engineers focus on the technological challenges of machine tools, automation systems, robots, etc. to realize a given product for a specific cycle time and cost. Managers within a manufacturing facility are often tasked with economic-related issues, e.g., budgeting, financing, and ensuring adequate cash flow. What is all too often overlooked, however, is that people are vital to the manufacturing enterprise. As a manufacturing firm seeks to transform natural resources, monetary capital, and knowledge into products that serve a societal need, humans play a critical role in every aspect of the enterprise. With this in mind, this paper explores how manufacturing impacts humans or groups of humans (social groups). It does not consider how society drives changes within the manufacturing enterprise (via the influence of demographics, educational level, gender roles, etc.). Rather, it is exclusively focused on the effect of manufacturing on society. In addition, this paper does not seek to make subjective or value judgments.

As evidence of its societal value, in 2014 industry was responsible for 31.1% of the $113.7 trillion global GDP [51], and much of this economic activity is attributed to manufacturing. As a result, manufacturers produced cars, refrigerators, mobile phones, televisions, clothing, food products, furniture, etc., all intended to meet the needs of and enhance the quality of life for society. In addition to meeting society's needs, manufacturing also provided employment for 22.3% of the 3.39 billion people within the global labor force [51]. Clearly, manufacturing plays a significant role in society around the globe.

The primary reason manufacturing exists is to provide the goods, services, and systems needed by society. To do so, manufacturing employs a large segment of society – and the money secured through this employment helps to support families and individuals. These are just a few of the positive social benefits of manufacturing. To further motivate this examination of the effect of manufacturing on society, let us briefly review some situations where manufacturing has negatively impacted social groups.

- From 2007 to 2015 there were numerous reports [30,138,197] of worker suicides at the Hon Hai Precision Industry (Foxconn) plants in Zhengzhou, Chengdu, and other Chinese cities. It was suggested that these suicides were attributable to mental health challenges and stress exacerbated by the working environment. Rather than address the cause, Foxconn asked workers to sign an anti-suicide pledge and installed steel cages around dormitory balconies and netting below the factory windows to stop the workers from plummeting to their deaths [86,89].

- In 1984, a Union Carbide pesticide plant in Bhopal, India released nearly 30 metric tons of methyl isocyanate. Hundreds of thousands of people were exposed to the resulting toxic gas cloud, and thousands of people were killed. This disaster had a tremendously negative effect on the community surrounding the manufacturing facility. What might not be expected, however, is this event led to a significant negative impact on competing chemical companies and supply chain partners [31,65,174,222,238,247].

- Nike has continually found itself criticized for its social responsibility performance. During the 1990s, there was a global boycott of Nike owing to accusations related to the labor practices (sweatshops) of its subcontractors. The boycott, driven by the actions of consumers and NGOs, deleteriously affected Nike's bottom line [43,79,151,216]. In response to the boycott and the associated stockholder uproar, Nike sought to transform its business practices and began monitoring the social responsibility of its supply chain partners [168].

In each of the above examples, manufacturing had an effect on individuals and stakeholder groups (Foxconn: workers, Union Carbide: local community, chemical industry, supply chain, Nike: supply chain, stockholders). Such examples begin to explain why firms are increasingly interested in social issues. This is evidenced through the increased attention to such issues as CSR (corporate social responsibility), triple bottom line, brand reputation, EPR (extended producer responsibility), outsourcing/reshoring, transparency, and the social dimension of sustainability.

Often a basic discussion of sustainability will begin with some form of the Brundtland definition [39]: meeting the needs of the present without jeopardizing the ability of future generations to meet their needs. Sustainability discussions also cover the need to embrace all three dimensions: environment, economics, and society. Fig. 1 offers a framework on how these dimensions interact with one another. Often, these three dimensions are referred to as the triple bottom line or 'people, planet, and prosperity.' Much has been written about the economics and environment dimensions, but far less has been contributed regarding the social dimension of sustainability. This paper seeks to summarize the work that has been done with respect to the effects of manufacturing on the social dimension of sustainability. With the goal to expand the knowledge of the manufacturing research community in terms of understanding the social dimension of sustainability, and in particular the role of manufacturing in affecting social groups.

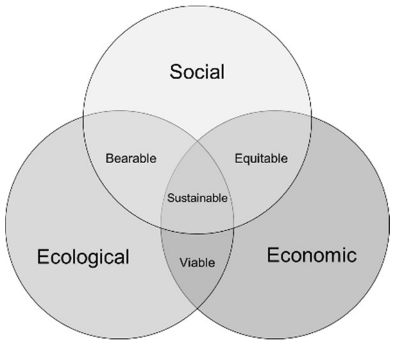

Fig. 1. The sustainable development framework including intersections (Bearable, Equitable, and Viable) of the three pillars (Ecological, Economic, and Social).

In terms of effects on social groups, we may define social impact as 'changes in physiological states and subjective feelings, motives and emotions, cognitions and beliefs, values and behavior,' that occur in an individual or social group as a result of the presence or actions of an entity [161]. Current research on social impacts focuses on changes within human interactions, organizations, relationships, and culture as a result of public or private actions. These changes can be physical, environmental, emotional, or intellectual, and further, can affect the way people live, work, play, connect to one another, unite to meet their needs, and generally survive as members of society [211,260]. From a manufacturing perspective, social impacts may be thought of as the direct or indirect effects felt by stakeholders due to a manufacturing enterprise.

The interconnectedness of our world is clearly visible in the modern supply chains of manufacturing companies, and the influence that manufacturing has across the supply chain Fig. 2. Over the last several decades, companies have seized the opportunity to source materials and products internationally in order to reduce their bottom line cost. Such an outsourcing/offshoring practice has often had detrimental effects on the local economies from which production was removed, and resulted in concomitant social disruptions. As might be expected, offshoring has generally had positive effects on the economies to which manufacturing has been newly located, and social consequences have also resulted. While globalization is motivated by economic issues, including the use of local resources for some products, manufacturers increasingly recognize that they must understand how local groups of people impact and are impacted by decisions. As people are often the most significant asset a company can cultivate, attention to the needs and characteristics of local groups is becoming a higher priority for companies.

Recently, the United Nations (UN) issued sustainable development goals [257], several of which include social impacts. As might be expected, the UN goals are focused on the measurement of social performance at a national level. While such national measures are important, they often provide little insight to a manufacturing enterprise that is endeavoring to improve its social performance. And, perhaps, this begins to get at the heart of the matter with respect to social performance. It is increasingly the case that there are tools that a manufacturer may use to reduce their environmental impact. Life cycle analysis (LCA), for example, asks a user to inventory their inflows and outflows for a given product across the life cycle to calculate the corresponding environmental impact. Methods such as 'design for the environment' and 'green supply chain design' may be utilized to reduce the environmental footprint of a product. So, what are the corresponding methods available to manufacturers from a social impact perspective?

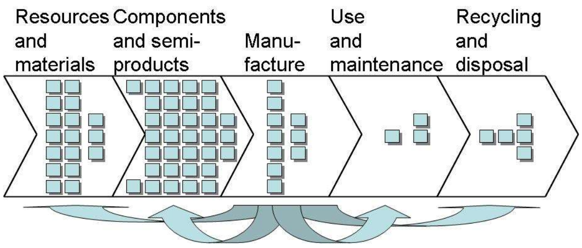

Fig. 2. The company designing and producing products exerts influence on large parts of the value chain [107].

The foregoing discussion motivates several questions. For example, what social effects are relevant to a manufacturing firm? What stakeholders are relevant to a manufacturing enterprise? How do we measure social impacts? What types of actions (or inactions) within an enterprise result in corresponding societal impacts? Are there tools that we can employ to quantify the total social impact across the life cycle? How do we simultaneously consider the three dimensions of sustainability: environmental, economic, and societal? This paper seeks to answer, or at least summarize efforts made in pursuit of resolution to these and other questions.

2. Social indicators and frameworks

As has been noted, sustainability addresses three dimensions: economy, environment, and society. When all three dimensions are satisfied over the long term, this can be thought of as being sustainable, as depicted in Fig. 1. Of the three dimensions or pillars of sustainability, perhaps the least is known about the social pillar, owing to the historically limited research on this aspect. The social dimension, specifically, is concerned with an extensive array of issues, e.g., safety, equity, diversity, governance, human health, labor rights, and justice. As such, the breadth of concepts allocated to this dimension creates a significant challenge when attempting to internalize and operationalize social sustainability.

Over the course of the last several decades, some progress was made in presenting collections of guiding criteria for social development. Many of these are applicable at a global or national level and therefore are useful when discussing a macro view of social impacts. The challenge to decision makers becomes which criteria apply, how to apply them, and if implemented, how to measure them. To paraphrase Lord Kelvin, in order to improve something, you must be able to measure it. This statement readily applies to social systems, which are increasingly of interest in terms of policy framing, economic development, philanthropic contributions, corporate decision-making, etc. Owing to increased visibility of affluent lifestyles through a digitally connected world, the global population has ever higher expectations for quality-of-life and standard of living. Being able to measure, evaluate, and improve on the social state of a variety of stakeholder groups is a missing piece in the sustainability puzzle. Further, there is not consensus on the tools and guidelines that are needed to measure and evaluate social performance.

To address social impacts, a set of definitions is needed. Currently there is not a consistent definition for measures, metrics, or indicators (MMIs). For this work, we will adopt the following definitions. A measure is a value that is obtained, relative to a standard, at a given time (e.g., infant mortalities). Generally, a measure offers little insight without a broader perspective. A metric places measures in context; a metric considers multiple measures so that comparisons may be made between products or processes. For example, an infant mortality metric may be the number of children younger than one-year-old that died in Country A during 2015. An indicator compares a metric to a meaningful baseline that can help guide actions, e.g., progress or achievement. An indicator can help to evaluate usefulness, suitability, efficiency, etc. often over time. [62,215]. From the previous example of metrics, change in infant mortalities in Country A from 2013 to 2014 to 2015 may be useful to the government of the country when formulating country policy. Examples can be clearly seen when relating social impacts to Gross Domestic Product (GDP) per capita, adjusted for Purchasing Power Parity (PPP). Increased economic prosperity by way of a higher GDP is directly related to both a decrease in infant mortality and an increase in literacy (Fig. 3). Often, several MMIs are selectively placed into an organizational structure or framework that may be used for further assessment, comparison, and model development.

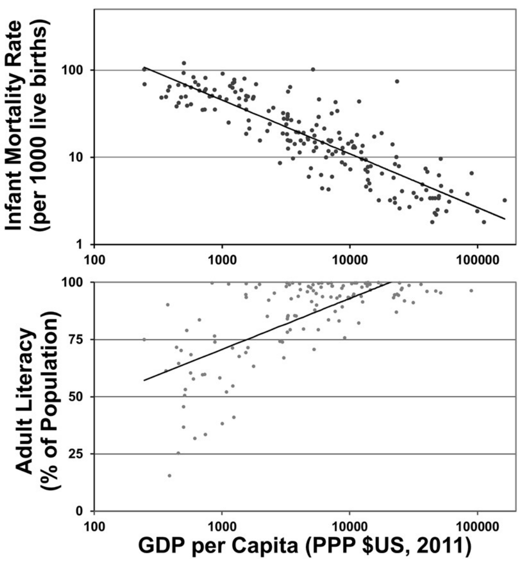

Fig. 3. National level indicator represented by (top) infant mortality (adapted from [127]), and (bottom) adult literacy vs. GDP per capita, in 2011 $US [258].

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With the foregoing definitions in place, and before examining the MMIs and frameworks that have been proposed for social issues, it is appropriate to briefly discuss the status of MMIs for the other pillars of sustainability: economy and environment. Some discussion of these dimensions will occur throughout this paper, since approaches used for one dimension may offer insight into how to approach for the social dimension. For now, emphasis will be placed on the general agreement that has been reached with MMIs. Economic MMIs have the broadest acceptance, with such values as cost, revenue, profit, and dividends all used to characterize performance. Accord is increasingly being reached on environmental MMIs as researchers, software developers, and company practitioners have driven convergence toward such MMIs as nonrenewable energy, greenhouse gas emissions (CO_2 equiv.), and resource consumption. The text that follows makes evident the fact that while MMIs and frameworks have been proposed for social issues, consensus has yet to be realized.

2.1 Early work on social issues

Social issues have been of interest for millennia. Highlights through human history include the Code of Hammurabi, the five books of Moses, Cyrus' *Charter of Freedom of Mankind*, Confucianism, the Magna Carta, the suffragette movement, and development of the UN. These all addressed aspects of community, social interactions, human rights, and justice.

Following World War II and the trials at Nuremburg, the Universal Declaration of Human Rights [113] was adopted by the UN General Assembly in 1948. The Declaration codified the importance of human rights established a global understanding of key social issues and expectations [201]. It took nearly three decades for the moral tenets described in the Declaration to be given political and legal support with the adoption (1966) and enforcement (1976) of the International Covenant on Civil and Political Rights.

The literature on social impacts has since expanded in response to the demand to guide, measure, and anticipate these impacts. The following section describes a few relevant guidelines, frameworks, and goals developed at the global and national level as well as some oriented toward industry. The timeline in Fig. 4 outlines several of the MMIs and frameworks discussed herein.

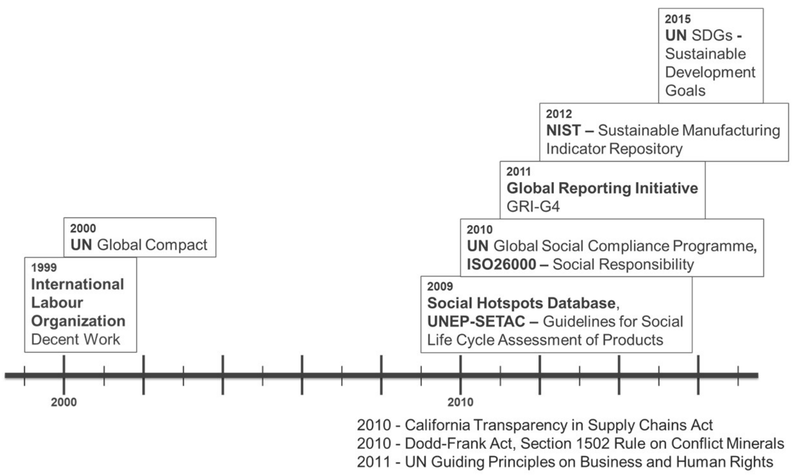

Fig. 4. Timeline for international and global frameworks, metrics, indicators, and laws associated with social sustainability.

2.2 Modern global and national-level MMIs and frameworks

Over the last quarter century, a push toward sustainable development has brought an expanse of global and national-level MMIs and frameworks into public awareness [5,6,17,66,110,125, 145,189,251].

To address social impacts associated with manufacturing decisions, there is a need for a robust set of sustainability indicators. These indicators should guide decision making, address relevant stakeholders, and allow for objective comparisons between options. Several frameworks, principles, and guidelines outline potential indicators and metrics to address social impacts within an organization [204,220,252,253,257]. However, the current landscape of existing frameworks does not include all of these characteristics. Other initiatives focus on corporate social responsibility and include ISO 26000: Guidance on Social Responsibility and Social Accountability International standard 8000 (SA 8000), which is an auditable social certification standard [134,228]. While these guidance documents are helpful, they are often interpreted according to the stakeholder and the context in which they are applied. Industry initiatives have also been developed due to lack of appropriate measures in place to address specific social impacts. Still, the available socially-oriented indicators may not be applicable in the manufacturing context. Acknowledging that many have attempted to incorporate two or more pillars of sustainability, the brief discussions in the subsequent sections focus exclusively on the social aspects of each framework.

2.2.1 UN Commission on Sustainable Development (1992)

Predating the frameworks reviewed in this section, is the establishment of the UN Commission on Sustainable Development (UN CSD) in 1992. The goal of this commission was to ensure the outcomes and agenda from the UN Conference on Environment and Development (UNCED), commonly referred to as the Earth Summit, were implemented and reviewed as needed. This included reviewing the progress of Agenda 21 and the Rio Declaration on Environment and Development. Agenda 21 addressed several social issues including combating poverty, promoting health, sustainable population growth, in addition to strengthening the role of major groups within communities and industry.

2.2.2 ILO Decent Work (1999), Decent Work Agenda (2008)

The International Labor Organization (ILO) is a UN agency that supports labor issues, social protection, and work opportunities for all [128]. The ILO advocates for productive employment and decent work are key elements to reducing poverty and achieving fair globalization. Within the global economy, the workforce is vital to manufacturers and their supply chains. The literature reports that work is a part of maintaining personal well-being [7,97]. Work provides income, stimulation, a sense of purpose and is an integral part of building and supporting communities. To ensure that work is decent and does not negatively impact individuals, the ILO defines decent work to include dignity, equality, fair income, and safe working conditions [128].

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In September 2015 at the UN General Assembly, the four pillars of the Decent Work Agenda - employment creation, social protection, rights at work, and social dialogue (detailed below) became integral elements of the new 2030 Agenda for Sustainable Development Employment creation [128].

- *Employment Creation* affords opportunities for investment, skills development, entrepreneurship, and sustainable livelihoods.
- *Social protection* ensures that women and men enjoy working conditions that are safe, allow free time and rest, honor family and social values, provide for adequate compensation in the case of lost or reduced income and permit access to adequate healthcare.
- *Guaranteeing rights at work* aims to recognize and respect all workers, especially disadvantaged workers that need representation, participation, and laws that are in their best interest.
- *Promoting social dialogue* increases productivity and fosters communication, strengthening the workforce and communities.

When successfully implemented and managed, decent work is beneficial to both the worker and the organization. To achieve this, a framework is needed that includes metrics and indicators to measure and identify progress. Ghai (2003) realized the importance of sufficient metrics to measure decent work and reviewed available indicators [97]. One key finding of this work was that the relevance of indicators to measure decent work varies between different groups and by location. There is also a need for more data, information, and a better understanding of the informal economy, i.e., nonstructured, nonmonetary transactions exchanging goods and services. The disparity between the formal and informal economy adds a layer of complexity when trying to build a framework and set of indicators that can be broadly adopted to measure decent work. One method used to account for this is the tiered approach clarifying three models of decent work: the classical model that includes countries characterized by high income per capita, transition countries identified as those moving from centrally planned to market economies, and finally the development model where these countries have a far greater diversity in their economic structures [97]. Developing indicators for decent work can be challenging due the variability across industries, regional considerations, and lack of consistency. Anker et al. (2003) attempted to overcome this by objectively measuring decent work [7]. The main goal was to develop a foundation for what constitutes 'decent work,' realizing that more research is still needed to understand how to effectively measure decent work.

2.2.3 UN Sustainable Development Goals (SDGs) 2015-2030

At the same meeting in September 2015 where the Decent Work Agenda was outlined, the UN adopted a plan for 'achieving a better future for all' which outlined 17 sustainable development goals (SDGs) [257]. The plan defines each of the 17 goals and includes strategies to operationalize and implement the goals to ensure their success. The SDGs provide a framework to guide the prioritization of sustainable development initiatives in industry at a global scale. Fig. 5 presents the SDGs and the range of goals that address social in addition to environmental and economic initiatives.

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Fig. 5. The UN Sustainable Development Goals (SDGs) [254].

2.2.4 United Nations Global Social Compliance Programme (2010)

The mission of the UN Global Social Compliance Program (GSCP) is to provide and promote a global best practice standard for sustainability in terms of supply chain management. This is pursued by hosting an open-source platform aimed at the multiple stakeholders in an organization. The GSCP provides information on buying companies, suppliers, service providers, and additional stakeholders. An integration of their technique can be seen in Fig. 6.

Fig. 6. GSCP approach to collaborative, sustainable global supply chains [47].

2.3 Industry-oriented MMIs and frameworks

One challenge for manufacturers is to define and understand the scope and boundary of social impact assessment. Indicators are needed across the supply chain and life cycle to account for social consequences of a company's activities. Many companies include a portion of these indices in their corporate sustainability report that outline the policies and practices related to labor and human rights within their operations. Social impacts need to be addressed within local communities and concurrently at the global scale (Fig. 7), making it even more challenging to develop robust social indicators within a manufacturing context.

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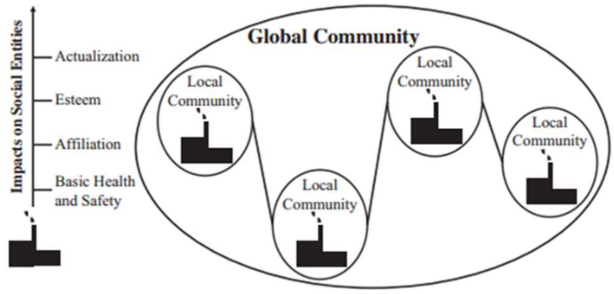

Fig. 7. Manufacturer's supply chain and social impacts [125].

2.3.1 UN Global Compact (2000)

The United Nations Global Compact (UN-GC) is an initiative to encourage companies and industries to adopt sustainable and socially responsible policies [250]. Part of the initiative is to have companies report on their implementation, fostering benchmarking and progress across a broad range of industries and organizations. It is the largest corporate sustainability initiative with 13,000 organizations across 170 different countries. Originally the compact included nine principles, later adding a tenth principal to address corruption. The principles are presented in Fig. 8. The principles primarily focus on social issues such as human rights and labor conditions, but also include three principles focused on promoting environmental responsibility. The principles are derived from several previous indicatives including the Universal Declaration of Human Rights, the ILO’s Declaration on rights at work, the Rio Declaration on environment and development, and the UN's Convention against corruption. Several resources have been developed through the UN-GC that includes guidance documents, frameworks, and best practices to help companies progress towards sustainable business practices. There has been criticism regarding the effectiveness of the UN-GC because the lack of enforcement provisions within the initiative that may allow companies to claim involvement without pursuing the goals set forth by the UN-GC principles.

Fig. 8. UN-GC principles to progress societal goals, adapted from [255].

2.3.2 Guidelines for Social Life Cycle Assessment of Products [251]

As introduced previously, the social dimension of sustainability is often difficult to quantify. LCA has a long history as a robust method for quantifying the environmental impacts of a product or process. With this, LCA provides an accessible and useful source of environmental data, but it is generally lacking in extensive information on human well-being impacts. This challenge has motivated the effort to incorporate social impacts into the LCA framework.

The UN Environment Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC) in conjunction with industry and academic organizations, developed the guidelines for social life cycle assessment (S-LCA) of products, referred here forward as 'Guidelines' (see also section 4) [251]. The Guidelines provide a historical perspective detailing the tools and techniques that have been directly informed methods and applications of S-LCA. The Guidelines detail the steps necessary to conduct an S-LCA, providing guidance on the common LCA steps described below in more detail: goal and scope, inventory, impact assessment, and interpretation. The framework detailed in the Guidelines is consistent with the ISO 14040 and 14044 standards for LCA. The framework categorizes social impacts by stakeholder as well as impact category.

The first step in conducting an LCA or S-LCA is the data collection of input and output process information. During this phase, the impacts for each stakeholder or life cycle stage are established. Data collection will vary significantly depending on the scope and the outcomes of interest. For example, if a study is primarily focused on health impacts, data may be collected using air quality sensors. If instead a researcher wanted to examine impacts related to labor, data could be found through work-hour logging systems as well as employee interviews. Following data collection and inventory, the information is analyzed using pre-defined metrics, in accordance with the study scope. The use of metrics allows for comparison across different systems, e.g., health impacts between two different facilities. One could use metrics to characterize exposure to harmful chemicals, accident frequency, and cancer rates.

While the Guidelines provide a robust framework, more work is needed to generate standard methods for interpretation of S-LCAs. Many researchers follow independent methods, leaving little room for comparison between studies [5,6,17,66,110,125,145,189,251]. Hutchins et al. (2013) conducted an S-LCA for a welding process and used 'increased risk of mortality from lung cancer' as well as 'risk of human and labor rights violations' as primary outcomes of interest [125]. Since a limited number of case studies are available, standardization is very difficult to achieve. Moreover, the range of metrics covering social issues is quite vast when compared with environmental or economic LCAs. Cross-disciplinary research around prioritization and clarification of social metrics will greatly aid the development of this burgeoning field.

2.3.3 Social Hotspot Database

The Social Hotspots Database (SHDB) (see section 4.4 and 4.5.3) was developed by New Earth and includes 22 themes within five social impact categories: labor rights and decent work, health and safety, human rights, governance and community impacts [23]. As the name implies, the database also provides hotspot characterization factors to qualify the severity and risk of the impacts. By linking the hotspots to economic trade as well as country and industry specific impacts, the database is useful across a broad range of industries and regions. The database includes risk factors specific to the life cycle process of concern therefore improving opportunities to intervene in the specific activities of concern within the manufacturing supply chain of a product. The database allows data to be obtained and validated among key stakeholders enabling cross-collaboration opportunities while maintaining transparency.

2.3.4 Sustainable Manufacturing Indicator Repository (2012)

Much like the previous two frameworks, the National Institute of Standards and Technology (NIST) developed the Sustainable Manufacturing Indicator Repository (SMIR) in which a category of social well-being was created to capture social performance indicators for manufacturing and manufactured products. Through an analysis of 14 existing indicator databases, the SMIR identifies subcategories of social groups impacted by manufacturing, i.e., employee, customer, and community. The social dimension is one of the five categories presented in the SMIR, and is limited in applicability across the entire supply chain of manufactured products.

2.3.5 ISO 26000 – Social Responsibility (2010)

ISO 26000 provides guidance on social responsibility that is applicable to public and private sectors in developed and developing countries. The goal is for this standard to develop an international consensus, present a connection from macro to micro applications, and refine existing practices. This systematic review allows for direct application of social responsibility for organizations, but is merely suggested guidelines and not certifiable like other ISO standards.

2.3.6 Global Reporting Initiative – GRI (2011)

The Global Reporting Initiative (GRI) is similar to ISO 26000, in that it seeks to address applications of social sustainability unique to organizations. UNEP and the Coalition for Environmentally Responsible Economics (CERES) developed the Sustainability Reporting Framework highlighting company-level environmental, economic, and social impacts. This system uses the following hierarchy:

1. Levels (e.g., social)
2. Categories (e.g., human rights)
3. Aspects (e.g., nondiscrimination)
4. Indicators (e.g., global policy on nondiscrimination including monitoring)

It ranks the indicators as core (most relevant to reporting organization) or additional (less relevant to reporting organization). An issue with this reporting program is that many of the indicators are qualitative or have binary condition. For instance, the examples an indicator on global policy is a binary condition, or a simple yes or no, but there is no qualification of the policy’s effectiveness. More descriptive quantifiable indicators are needed in order to improve the reporting system and allow comparability from year to year.

2.4 Corporate social responsibility (CSR)

Within business, management, and economics, different researchers have interpreted Corporate Social Responsibility (CSR) differently. While the basic foundation of the idea is understood and agreed upon, the specific context of the details remain subjective, with an overarching consensus yet to be achieved. For the purpose of this discussion, the World Business Council for Sustainable Development (WBCSD) offers a definition that is both understandable and independent of environmental considerations, stating that CSR is 'the continuing commitment by business to contribute to economic development while improving the quality of life of the workforce and their families as well as of the community and society' [267]. A slightly broader definition given by the Commission of the European Communities is suitable as it also considers the voluntary nature of integrating social and environmental concerns into business operations [58]. It must be noted that CSR in modern business practice equally emphasizes the social and environmental dimensions, and is seen as a tool, commitment, process, and/or principle [63]. In short, CSR may be succinctly stated by saying that an enterprise is responsible for the impacts created by its operations that affect stakeholders, both positively and negatively, directly and indirectly, while pursuing profitability and growth.

The origins of CSR date to before World War II, but really gained shape with Bowen's Social Responsibilities of the Businessman [35]. The following years defined, refined, and argued the merits of CSR. One notable contribution was Milton Friedman's (1970) assertion that the only social responsibility of business is to increase profits, where a democratic free society will handle associated social issues [93]. Seemingly in response to Friedman's position, many have proposed, debated, and endeavored to prove the business case for CSR [46], culminating in the tenet 'doing good to do well' [264]. In short, CSR is often supported not only by business leaders, but by corporate boards as well [140].

Although there 'seems' to be empirical evidence supporting the positive association between social performance and financial performance [175], the causal link remains unclear, which echoes the current understanding of social indicators. Baron et al. (2011) found that in consumer markets, financial performance increases positively relative to social performance, which is not the case observed for industrial markets [15]. These findings present a clear challenge for widespread adoption of CSR in the manufacturing sector that would benefit from a consensus on a rigorous approach to employing CSR. Not surprisingly however, is the research supporting that firms with better CSR performance face significantly lower constraints when accessing capital [48]. Interestingly, the benefits often attributed to CSR activities include such things as improved brand awareness, cost and risk reduction, enhanced competitive advantages, and synergistic value creation. There is no shortage of indices and auditing frameworks related to CSR [263], offering measures that compare businesses to one another, e.g., Dow Jones Sustainability Index (DJSI), Thomson Reuters Environmental, Social and Governance Indices, the Corporate Responsibility (CR) Index, and the GRI. In a manufacturing context, many view CSR as limited to the immediate reach of the company; however, it is clear that industry reach extends beyond the boundary encompassing a manufacturing facility.

Reviewing CSR policies across industries and comparing companies presents clear evidence that no comprehensive initiatives exist [28,200]. Therefore, decision-makers in organizations have a challenge when implementing CSR best practices across an enterprise. What is best for the stakeholders outside the company might not be best for the organization as a whole, so transparent reporting of social issues becomes a question of ethical responsibility. A manufacturer and associated supply chain then runs the risk of brand damage as well as relinquishing competitive advantages. Nonetheless, utilization of CSR is a foundational metric of Socially Responsible Investments (SRI).

2.5 Summary

The social dimension of sustainability is concerned with an extensive array of issues, e.g., safety, equity, diversity, governance, human health, labor rights, and justice. Due to this breadth of issues, there are significant challenges when attempting to internalize and operationalize social sustainability, especially in a manufacturing context. Progress has been made in establishing criteria for social development, especially at a global or national level, but still greater detail is required. These macro level criteria are useful when discussing a systems view of social impacts. This section also introduced a set of definitions for measures, metrics, or indicators (MMIs). A number of the more prominent modern global and national-level MMIs and frameworks were reviewed.

A continuing challenge for manufacturers is to define and understand the scope and boundary of social impact assessment. For this, indicators are needed throughout the supply chains and life cycle to account for social consequences of a company's activities. A number of these industry-oriented MMIs and frameworks are reviewed. Finally, CSR as a policy for corporate behavior is examined. Although widely used, CSR best practices remain subjective and inconsistent, and with respect to business metrics, a positive association between social performance and financial performance is not clear.

3. Effect of manufacturing on social performance

As noted in the preceding section, many identified frameworks and indicator sets consider broad categories of impacts that may have limited utility at the local level. For example, while national levels of social performance, e.g., infant mortality, education, cultural heritage, migration, are important, a manufacturing enterprise may be hard pressed to understand how their day-to-day activities relate to any one of these social MMIs. The aforementioned national MMIs are perhaps of little use to a manufacturing enterprise trying to decide the best opportunity to positively impact social. There is little systematic understanding for the application and measurement of these MMIs and frameworks, making an objective process difficult to implement [211]. Further, the social issues resulting from industrial activity have not generally been approached with an engineering mindset, which makes measurement and analysis challenging.

The gap between measures that are appropriate at a national level and those that are meaningful to a company often relates to scale or scalability. With scale, the appropriate measures of social performance can vary greatly depending upon the scope of the entity under consideration, e.g., from national to manufacturing enterprise to manufacturing operation levels. Often, the measurement of social performance only occurs at a nationalized level, resulting in an aggregation of impacts. These aggregated datasets are typically nonrepresentative depictions of the local system. Even though an enterprise may have facilities across the world and a supply chain that touches nearly every continent, the groups of workers at different facilities may vary significantly. These differences could be due to geography, policy, product type, or a complex combination of other factors. Nonetheless, local/cultural knowledge is generally required to create solutions that are in the best interest of the enterprise and all of its stakeholders. This means that the social information may need to be disaggregated to provide appropriate local social knowledge at the regional, enterprise, facility, product, and process level or, that entirely new social data be collected for the application of interest.

This section will explore the stakeholders and social impacts that are relevant to a manufacturing enterprise. In addition, some discussion will be presented on measurement and assessment tools, and approaches that merit continuing investigation to understand how manufacturing actions affect social performance.

3.1 What is a social impact?

As introduced previously, a social impact may be thought of as the direct or indirect effects felt by stakeholders. Direct impacts are often clearly identifiable, measurable, and bounded spatially, whereas indirect impacts need not be in close proximity (either physically or conceptually), to a firm. This ambiguity of indirect impacts is identified in ISO 26000 explaining that an organization may not always consider every stakeholder, and similarly, stakeholders may not contemplate the potential effects on their interests [134]. A stakeholder may still 'feel' the impacts as a ripple effect, e.g., changing packaging on a product to a renewable material increases income for small farm owners (indirect stakeholder) of Forest Stewardship Council (FSC) certified materials.

Considering the scope of manufacturing, an enterprise will create social impacts by simply existing, as the well-being of employees, customers, owners, and local communities are tied to the operations [72,149,176,271]. Through manufacturing processes, the enterprise creates observable and measurable impacts on these social groups. Impacts can range from the positive, e.g., increasing literacy or facilitating gender equity, to the undeniably negative, e.g., promoting slavery or allowing gender or ethnic discrimination, or fall somewhere in between, e.g., employing child labor or encouraging working time that exceed country-allowed maximums.

The Guidelines (2009) provide a comprehensive classification of social impacts by relating consequences of actions over the entire product life cycle to stakeholders and measurable impact categories. The categories considered were human rights, cultural heritage, governance, health and safety, working conditions, and socio-economic repercussions, or more generally, human well-being [251].

3.2 Social needs

Human beings exist as complex networks of highly variable, interconnected systems [186,207,240]. To understand the core of this complexity it is necessary to understand the motivation for human behavior. Maslow (1954, 1958, 1970) developed a hierarchy of human needs in order to categorize the driving forces behind human behavior [181-183]. At the most basic level, needs can be characterized as the physiological requirements that are critical to survival, e.g., water, food, clean air, clothing, and shelter. These basic needs have defined boundaries for achievement. For example, the number of calories needed per day or the quantity of water the body needs to avoid dehydration. The literature generally presents physiological needs as MMIs within the context of poverty or health, but extends to financial concerns when discussing basic needs of a firm. The hierarchy makes clear that without this basic level satisfied, the individual or group would be challenged to achieve a higher order need. However, if the basic physiological needs are sufficiently fulfilled, they become trivial in the dynamic systems of the individual or group [180], and need for safety and security becomes the next motivating factor. The hierarchy illustrates the subsequent higher-order needs as affiliation, esteem, and actualization, respectively (Fig. 9). In essence, when one need level is fulfilled, the next higher level is pursued.

Maslow's hierarchy was originally intended to characterize the needs of an individual, but has been used to evaluate the needs of stakeholder groups for a manufacturing enterprise [123]. The following section will discuss stakeholders for a manufacturing firm, their associated indicators and impact categories, and finally their needs using Maslow's hierarchy as a framework.

Fig. 9. Maslow's Hierarchy of Needs (adapted from [180,182]).

3.3 Stakeholders of a manufacturing firm

As we consider the impacts that a manufacturing enterprise has on social groups, the first issue to address is who the relevant stakeholders are. We need to explore what a stakeholder is and discuss the needs of each stakeholder group – all from the perspective of a manufacturing firm. It is important to note that for each stakeholder groups there exists a 'future generation.' From the literature, it is evident that overwhelming focus is limited to what is happening right now, and long-term perspectives for social issues are rarely considered. Given that the concept of sustainability seeks to ensure access to resources in the long-term, future generations must be considered. Reflecting on our present state of knowledge and the complexity of systems involving technology, natural resources, and human/group behavior, forecasting future stakeholder states is likely to remain elusive, but is nonetheless a worthy goal [77,146,209].

In order to understand social impacts on stakeholders, it is essential to explore the direct and indirect stakeholder groups affected by a manufacturing enterprise. A stakeholder is an individual or group of individuals who are affected by the achievement of an organization's objectives [90]. Freeman (1994) further defines stakeholders as participants in 'the human process of joint value creation' [91]. This sentiment emphasizes the importance of humans to a manufacturing enterprise. Fig. 10 identifies an example set of stakeholders for a firm.

The Guidelines (2009) define stakeholder categories as groups of stakeholders with shared interests in the investigated product system within the context of a product life cycle. The Guidelines also note that additional categories, e.g., NGOs, public authorities, and future generations, can be defined based on the needs of an enterprise, depicted in Fig. 11 [251].

To identify stakeholders of an organization, ISO 26000 asks a series of qualifying questions addressing legal obligation, affected and 'vocal' groups, groups with needed resources, and groups disadvantaged if excluded [214]. This stakeholder discovery overlooks both indirect stakeholders and impacts, which therefore become uncounted externalities.

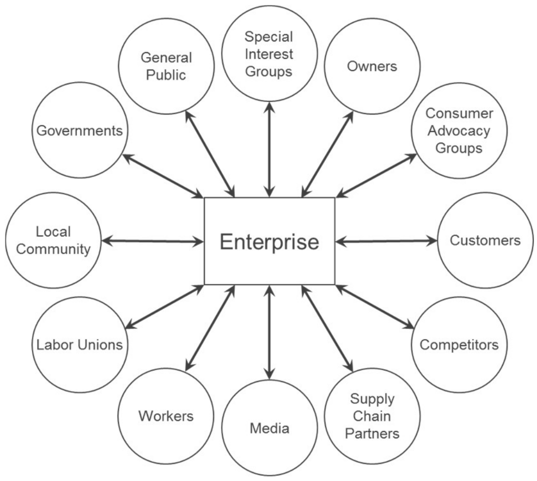

Fig. 10. Example stakeholder groups impacted by/impacting a firm (adapted from [90]).

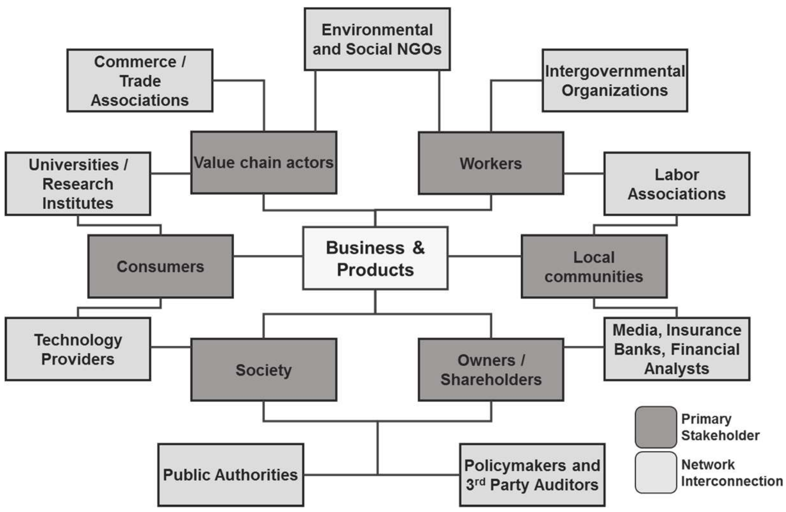

Fig. 11. Hub and spoke diagram of stakeholders impacted by/impacting a firm (adapted from [251]).

3.4 Stakeholders and indicators

There is a significant volume of literature exploring stakeholder groups [1,24,33,44,56,68,81,91,95,104,105,123,141,163,188,196,241, 243,251,272,273]. Considering that this literature is drawn from various disciplines, e.g., behavioral sciences, economics, and engineering, each contribution adopts a slightly different perspective. Notably, stakeholders can exist in several groups simultaneously, e.g., customer and local community, worker and shareholder. Generally accepted stakeholders of manufacturing will be discussed, including some existing subcategories and indicators that allow for measurable impacts on each group of stakeholders. There is additional discussion of metrics and impact indicators for these stakeholder groups later in this paper. Finally, utilizing the framework in Section 3.2 based on Maslow's needs hierarchy, examples of stakeholder needs at varying levels will be discussed.

3.4.1 Workers or employees

While there is a theoretical and legal differentiation of worker and employee [198], we will use these terms interchangeably. A worker/employee is simply an individual who provides their skills to a firm, usually in exchange for a monetary wage [123]. More specifically, in 1993, the ILO clarified a need for 'stable contracts' in which employees have had a contract of employment, explicit or implicit, written or oral, with the same employer, continually [122,130].

Workers or employees are the most evident direct participants as a stakeholders due to the measurable impacts on them as a group, an idea which is heavily supported by [44,70,98,123,164,251]. This group has accessible datasets enabling quantifiable impacts from manufacturing. This does not imply that because data exists, measuring social impacts is straightforward or easy. Rather, it indicates that this stakeholder group has been extensively evaluated over time.

According to the ILO, employees (i.e., those not self-employed) comprise 60-90% of the employed population, with 80% of workers in developed regions. On the other hand, in less developed countries, this percentage may be below 15% of total employment [129]. This highlights that across all sectors, employees are the foundational social element of production, but are not often recognized contractually as such in developing countries. Being the principal stakeholder, workers experience measurable impacts and have more clearly identifiable social impact categories and indicators than other groups. UNEP/SETAC has identified a set of impact categories and corresponding subcategories for the employee/worker stakeholder group (see Table 1) [24,251].

Table 1 Sample of impact indicators for stakeholder 'worker' [24,83,251].

Group	Subcategories	Indicators
Worker	Freedom of Association and Collective Bargaining Child Labor Fair Salary Working Hours Forced Labor Equal opportunities / Discrimination Social Benefits / Social Security	Recordable injury rate Lost workdays Blood lead level Sick days Personal protective equipment Employee knowledge empowerment Training hours Job satisfaction

Hutchins (2010) explored social impact indicators (SIIs) by a series of Delphi surveys intended to find a single 'best representative' indicator of the impact category, for all stakeholder groups and every need level. For employees, these indicators range from basic needs for financial compensation to higher order (and more difficult to quantify) needs of providing a valued contribution to the company [124]. Contrarily, the SMIR aggregates 30 employee social well-being indicators ranging from 'Blood lead level' to 'Job satisfaction' stemming from reporting found in the DJSI [83]. Joung et al. (2013) highlight the employee category SIIs covering health and safety of employees, professional development, and satisfaction, going further to explain the importance of employee as a stakeholder group due to the close relationship between product quality and employees in manufacturing [145].

3.4.2 Owners or shareholders

The owners or shareholders group can be thought of as owners, financiers, or stockholders [61]. Hutchins et al. (2010) describe the owners as individuals, groups, or organizations with a financial investment in a business [124]. This group is referenced frequently through management and economic literature in the context of CSR. This stakeholder group is presented herein as large shareholders, but acknowledge that this assumption excludes the smaller individual investors and shareholders. While nonetheless important, these smaller investors may have little influence on the direction or decisions of a firm.

In practice, separating this stakeholder group from the enterprise is difficult due to the intimate link tying corporate performance to leadership and vision. The delineation is necessary however, to understand how owners and shareholders are impacted by actions of the manufacturing enterprise. Interestingly, other disciplines appear to have the goal of informing this stakeholder group about all others stakeholders while not explicitly acknowledging that this group itself can experience social impacts in addition to economic ones. As evidence of this, many investors prefer to put their money in socially responsible equity funds – perhaps this is because of the social benefit received from 'doing the right thing.' Consider the growth of SRI and Environment, Social and Governance (ESG) indexes, e.g., S&P 500 Environmental & Socially Responsible Index (SPXESRP), iShares MSCI KLD 400 Social Index (KLD), the suite of Calvert Responsible Index Series, and the DJSI, and the concomitant increase in assets managed in socially sustainable funds, e.g., Domini Social Equity (DSEFX), Parnassus Equity Income (PRBLX), Pax World Funds (PXWGX), and TIAA-CREF Social Choice Equity (TISCX and TICRX). Fig. 12 highlights the trend of increasing sustainable investing over the last 20 years. An argument has developed whether or not SRI leads to increased economic returns, where the majority of reports tend to support the affirmative [15,26,46,73,140,170,200]. This discussion demonstrates how modern shareholders value social benefits in addition to economic utility over the long-term.

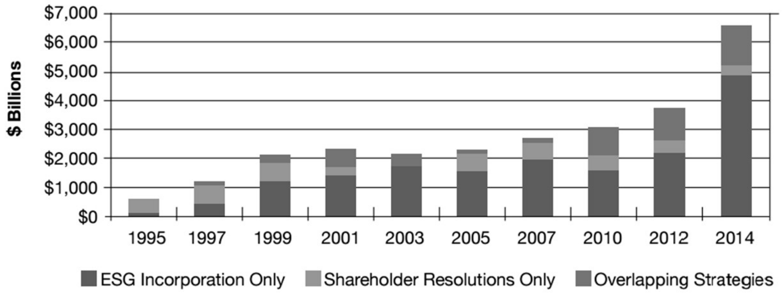

Fig. 12. Sustainable and responsible investing in the United States 1995-2014, adapted from [266]

Mitchell et al. (1997) suggest that this stakeholder group is dominant to the decisions of a firm due to financial investment, but can become demanding when legitimate interests are not being served [191]. This seems to attach the moniker of 'creating the impact' instead of also 'receiving the impact.' Take for example in 1993, when stockholders of IBM, General Motors, Kodak, Westinghouse, and American Express felt management was responsible for plummeting stock prices. The response to remove management was swift, demonstrating a significant urgency and forcing these companies to consider the consequences of inattention to owners' claims. Nevertheless, owners or shareholders, while guiding the direction of the enterprise and likely responsible for many decisions beyond the product, process, and managerial levels, seem to have higher associated needs with their respective impact categories (Table 2). Through Delphi surveys, Hutchins (2010) identified that basic needs were financial rate of return on investment, where security needs reflected risk management concerns [124]. An example of esteem needs for this stakeholder group is not only having the right to vote within the organization but also voting.

Table 2 Sample impact indicators for stakeholder 'Owner' [124,126].

Group	Subcategories	Indicators
Owner	Transparency Contribution to economic development Corruption Equal opportunities / Discrimination	Financial accountability Financial security Philanthropic opportunity Validation of decision to invest Aligned interests Voting rights

3.4.3 Consumers or customers

Garvare and Johansson (2010) provide an insightful review on the definition of a customer, highlighting an Ishikawa (1985) coined phrase, 'the next process is your customer [131]' [95]. Clearly, the assumption is that the customer/consumer is the top priority for an enterprise. This status can be seen in corporate documentation over the last century, e.g., General Electric in 1933 beginning a formalized stakeholder concept acknowledging customers, Johnson & Johnson in 1947 leading to the company's business credo in responsibility to 'doctors, nurses and patients, to mothers and fathers…who use our products and services [139],' and Sears in 1950 listing 'four parties' in order of importance with customers as first priority [217]. Protection of this social group has an even more storied past from the creation of the US Federal Trade Commission in 1914 through Consumer Protection Acts of the 1960s and 1970s, to the UN Guidelines for Consumer Protection (UNGCP) of 1985.

In general terms, this stakeholder group is viewed as any end-user of a product, service, or process. This is not limited to individuals, however, and with a life cycle view, would include the next downstream link in the supply chain. Consider a manufacturer of printed circuit boards (PCBs) who has several consumers/customers, e.g., component manufacturers, assemblers, repair, or do-it-yourself (DIY) enthusiasts. Each of these consumers has a different need, or function, to be fulfilled by the PCB manufacturer. This example highlights the range of indicators that can be used for this case-by-case, context specific stakeholder group. Hutchins (2010) found the indicator best representing actualization needs of the consumer/customer group is the percentage of customers who believe company products or services greatly improve their quality-of-life [124]. Table 3 presents a sample set of somewhat qualitative SIIs suggestive of the multiple needs levels for the stakeholder group customers or consumers.

Table 3 Sample impact indicators for stakeholder 'Consumer' [24,83,251].

Group	Subcategories	Indicators
Consumer	Health & Safety (H&S) Feedback Mechanism Consumer Privacy Transparency End-of-life responsibility	LCA for H&S impacts Customer satisfaction assessment Customer complaints Breaches of privacy

3.4.4 Suppliers or value chain actors

Suppliers or value chain actors are stakeholders that provide goods or services for use by a firm. An individual firm has the potential to have many suppliers at a given time, across multiple product lines. When taking a life cycle view, suppliers can be considered the next upstream link in the supply chain. Historically, there have often existed somewhat adversarial relationships between suppliers and manufacturers. More recently, however, these relationships have developed into more mutually beneficial partnerships. Beyond the immediate first tier relationship, manufacturers must also consider the entire supply chain, adding significant complexity a life cycle sustainability analysis. This analysis must also now include the social impacts of every supply chain partner. With increased attention to social sustainability in supply chains over the last decade [13,14,57,94,126,177,194,213,227,236,237,270,273], the scientific community has attempted to quantify life cycle social impacts of their products (see section 4.1) [11,19,69,74,152,158,187,239,251]. Firms are increasingly choosing suppliers by measures beyond price, e.g., quality, location, service, social responsibility, and commitment to philanthropy. Consider a manufacturer of electronic devices that finds child labor in an audit of supply chain partners. Instead of terminating the underage worker and penalizing the partner, the manufacturer collaborated in funding youth education programs and supplementing the lost wages, while further guaranteeing a job when schooling is completed. In the short term, the financial cost may seem not worth the investment, but a loyal employee and stronger supply chain partnerships offer long-term value creation.

Hutchins (2010) identified a clear indicator for the basic needs of the supplier stakeholder group [124]. Similar to workers and owners, financial compensation by on-time payments of invoices seems to be the most suitable indicator. Beyond the safety and security needs indicator of breached contracts, the higher order needs of this group are much more difficult to understand, leaving room for deeper research and analysis. Table 4 presents a sample subset of indicators for the supplier stakeholder group; most of the indicators are quantitative measures in the form of ratios. Notably, these indicators hint at consideration for competitive suppliers.

Table 4 Sample impact subcategories for stakeholder group 'Suppliers' [24,124,251].

Group	Subcategories	Indicators
Suppliers	Fair competition Promoting social responsibility Supplier relationships Respect of intellectual property rights	Invoices paid on time Ratio of contract length to industry average Percentage of contracts failed/breached

3.4.5 Local community

The stakeholder group, local community, is defined very differently among disciplines [3,25,60,154,159,221], but the same general principle of a spatially-related agglomeration of individuals utilizing a shared resource base within which a firm exists. For example, in natural resource management, there could exist a spatial limitation to the mining reserves for metal deposits, and the people living in the area might be considered the local community. Another example might be an industrial complex where several industries with diverse manufacturing facilities work in the same vicinity, potentially sharing resources and transportation networks [225]. The infrastructure and function within a local community also ranges in complexity, but from the nano- to the micro- to the macro- levels, interconnectivity of the community network will often define success and resilience [172,271] – stating simply that sharing and communication are necessary for a prosperous community. Difficulty comes with drawing spatial boundaries around a local community. These boundaries are extremely context specific, and just as in S-LCA, boundaries must be defined to limit the scope of negative impact (or broaden the scope for positive impacts), with tools such as Geographic Information Systems (GIS), useful for integrating the spatial dimension of social data.

The spatial element is not the only limitation when defining the stakeholder group local community. Understanding the needs of a local community can present a significant challenge as well. Basic needs might be as simple as taxes paid by a company or intangible resources such as access to information or community services, where affiliation needs might be the percentage of employees who come from the community itself [124]. Furthermore, this stakeholder group is viewed as indirect leaving impacts highly qualitative (Table 5).

Table 5 Sample impact subcategories for stakeholder group 'Local community' [24,83,124,251].

Group	Subcategories	Indicators
Local community	Access to material and intangible resources Community engagement Safe neighborhoods Delocalization and migration Cultural heritage and indigenous rights Safe & healthy living conditions	Legal actions for anti-competitive behavior Salary ratio Human rights training Discrimination Anti-corruption training Political contributions Conflict of interest Employees from local community

3.4.6 Global society or general public

All other social groups outside the bounds of those already listed fall into the category of global society. State, national, and international government entities as well as many of the network interconnections (Fig. 11) also fit within this category. Consider the supply chain of a pet food manufacturer and the corresponding stakeholders, e.g., worker, customer, owners, suppliers, and local community. If this pet food manufacturer counts fish as a protein source, the location in which the fish are caught and the manner by which they were processed dictate the sustainability of the operations, but moreover, the global food supply chain is impacted. The broad impacts of the global society stakeholder can be viewed through the idiom, 'do well by doing good,' where the action taken to create positive impact craft a common good [10,103]. The common good is a shared resource for all stakeholders, inasmuch as the oceans, air, and land provide natural resources, the global society provides physical, intellectual, and creative resources for industry. In turn, the impacts created by manufacturing on the global society are captured by subcategories and indicators found in Table 6. Hutchins found that while basic and safety and security needs for society still required clarification, the higher order needs such as esteem represented by company publications addressing sustainability, or actualization as ratio of philanthropic giving to market value, presented fairly clear evidence that being a good corporate citizen was indication of positive social impact overall [124].

Table 6 Sample impact subcategories for stakeholder group 'Society' [24,124,251]

Group	Subcategories	Indicators
Society	Public commitments to sustainability issues Contribution to economic development Prevention & mitigation of conflicts Technology development Corruption	Ratio of financial to in-kind contributions for NGOs Anti-corruption program Partnerships in R&D Incorporated SDGs in sustainability reports

3.5 Cross-disciplinary work on social impacts

Understanding of social impacts and how to evaluate them has developed broadly through three complementary but often disconnected disciplines: behavioral sciences, economics, and most recently, engineering. The breadth of research in the two former disciplines is established, often reviewed and updated frequently with new research methods and case studies [38,40-42,45,59,67,80,92,96, 102,137,153,200,203,211,226,260,261]. In turn, engineering has gained significant traction over the last decade by integrating contributions of the other disciplines into LCA techniques [70,75,84, 107,119,202,210,223,268]. Further, when looking at the time-frame considered by each discipline, the perspectives range from reflective (past), through the current situation (present), to predictive (future). A decision-making challenge is clearly evident when observing this temporal complexity. For successful social sustainability evaluation, the time element must be considered to understand the social impacts of manufacturing. With this in mind, it is necessary to recognize that these fields are not mutually exclusive. Rather, they should all be leveraged to provide a more comprehensive view on how social impacts are tied to manufacturing.

3.5.1 Social impact assessment (SIA)

Social impact assessment (SIA) generally refers to the calculation of the impacts (effects or consequences) that are likely to be experienced as a result of some proposed action [92]. The concept of SIA was expanded to include forecasting the effect of policy actions or project implementation that may result from environmental legislation [41]. The United States Interorganizational Committee on Guidelines and Principles for Social Impact Assessment (GP-SIA, 2003) summarizes SIA as a decision tool that includes social and cultural factors, incorporates local knowledge and values, and helps identify the most socially beneficial course of action for multiple level policy decision-making [211]. The International Principles indicate that the primary purpose of SIA is to 'bring about a more sustainable and equitable biophysical and human environment' [260]. This section will not explore the most suitable definition or the capacity for prediction, but instead will attempt to facilitate a connection between manufacturing and SIA, beginning with a brief history and closing with some recent developments.

SIA shares its origins with environmental impact assessment (EIA) that was originally conceived by the United States National Environmental Policy Act (NEPA) of 1970. NEPA required social issues to be considered as part of the environment, but provided no guidance on how to measure them in a meaningful way. The term SIA likely developed out of the concern for changes in customs and cultural norms experienced by the indigenous people (Inuit) during the Alaskan oil pipeline development in 1973 [41]. SIA gained national recognition in 1985 with the US government indifference to the social, cultural, and economic impacts on the Northern Cheyenne Tribe by the US Department of the Interior over a $4B federal sale of coal [92]. In 2003, both the GP-SIA and the International Principles developed guidelines for SIA, where the former attends to be data driven by technological assessments and the latter focuses on democratic stakeholder participation [211,260,261]. Put simply, an issue is who decides what is best: engineers/designers or stakeholders that will be impacted. Regardless of the method used, the intent for SIA has always been to better understand the anticipated social impacts from major projects [80]. Certainly, applying this to manufacturing is a logical undertaking.

It must be noted that SIA is most often included as a subcomponent of EIA and not typically an independent practice. In 2014, observing a need for a tangible and easily implementable tool for companies, the Roundtable for Social Metrics, an interdisciplinary industry-led consortium, developed the Handbook for Product Social Impact Assessment v2.0 in cooperation with a diverse set of external stakeholder groups. The method presented a life cycle view for a product or service with the purpose of identifying social impacts, both negative and positive, to drive innovation and transparency in business operations [88]. Fontes et al. (2014) further stated that the methodology is 'not yet aligned with other ongoing global initiatives,' but recognized that as social metrics continue to evolve and gain greater consensus, cooperation and collaboration will drive acceptance [88].

Several others have expanded, consolidated, and presented 'best-practices' of SIA along with integrating social risk assessment and uncertainty analysis [8,18,166,173]. Following these research developments, a combined impact assessment method was proposed: environmental plus social - identified as ESIA. Only recently has this hybrid method been explored by the scientific community (while having been widely practiced internationally by the banking industry) [64]. Hutchins and Sutherland (2008) have suggested that while industry is presently evaluating social impacts (application), the research community is just beginning to establish the requisite underpinnings needed to support such evaluations (theory) [126].

3.5.2 Comparing CSR to SIA

Both CSR and SIA attempt to address business activities and the resulting social effects such as human rights, community involvement, and ethical behavior. The greatest similarity between SIA and CSR is the rapid pace at which industry has adopted each (albeit largely selectively and subjectively). This adoption has proceeded faster than the rate of research to support industry efforts. Historically both CSR and SIA were applied in 'one-off' scenarios, typically philanthropic or reputation-based, and in general there was not a holistic, company-wide approach or program established to support social progress [106]. Whereas SIA has typically been driven by policy and CSR has been voluntary, there are notable exceptions. For example, Section 135 of India's Companies Act, better known as the CSR Law, obligates corporations to address poverty, education, hunger, healthcare, and gender equity, among many other social issues [192]. This policy has received mixed reviews yet remains a visible example of an effort to affect social change. While CSR is internal to a corporation, SIA is often an outsourced activity that requires third-party involvement. Delegating responsibility to an outside party often leads to incongruences between the SIA results and the implementation of changes that can positively affect corporate decisions [27]. The potential for integrating SIA and CSR into corporate decision-making is an opportunity for a comprehensive social impact evaluation at the company level. In this context, CSR may be used to set the direction of a company related to social issues, and then SIA may be used to measure, reinforce, modify, and adapt CSR policies according to SIA findings.

4. Social life cycle assessment (S-LCA) methodology

4.1 Product life cycle perspective for social impacts?

Emphasis on the social sustainability of supply chains [252] and policy frameworks such as the UN Sustainable Development Goals for 2030 [256] (as operationalized through the Global Social Compliance Programme and ISO 26000's Guidance on Social Responsibility [47,134]) calls for shifting corporate focus from shareholders to include all stakeholders. Attention is shifting to direct accountability towards customers, employees, and the communities that in one way or another are influenced by manufacturing activities.

It is recognized that the decisions of designers and strategic decision makers have economic, environmental, and social impacts across the product life cycle [107,147,160,248]. Take as examples electronic equipment, cars, and renewable energy products. While these products are used around the globe, their design is defined by specific companies and they are produced and their material content of precious or scarce metals is extracted from selected locations across the world, often in emerging economies under dire conditions [212]. Dramatic growth of some manufacturing sectors, e.g., wind energy [100], drives exponential growth in primary production [150] that may be associated with adverse social effects in material extraction [120,208]. Thus, decisions typically made in the richest part of the world to outsource production (typically to much poorer parts of the world) are responsible for also outsourcing social impacts. In principle, these decisions should seek to internalize product/process/service externalities.

Sutherland JW, Richter JS, Hutchins MJ, et al (2016) The role of manufacturing in affecting the social dimension of sustainability. CIRP Ann - Manuf Technol 65:689–712. doi: 10.1016/j.cirp.2016.05.003

For a company that wants to behave in a sustainable manner, S-LCA is a valuable conceptual framework and methodology. It allows for the identification and accounting of social impacts that occur in other parts of the world, and put into practice the adage that 'with influence follows responsibility.' S-LCA considers the life cycle of services or products and relates them to the social entities that are part of or are affected by the decisions made by designers and other decision-makers within a company's value chain [107,248]. S-LCA thus encompasses life cycle thinking, targets stakeholder inclusiveness, and may even align with such broader policy concepts [99] as 'sustainable innovation', corporate social responsibility (CSR), and holistic life cycle oriented management [34,224,230].

S-LCA was introduced at an LCA method development workshop in 1993 under the auspices of the Society of Environmental Toxicology and Chemistry (SETAC), but little activity took place in terms of methodological development until a decade later [20]. The inspiration came from methodological considerations in environmental LCA which had been standardized in the 1990s [132,133]. The epistemic S-LCA community, which has evolved since, largely includes participants from engineering and environmental science, drawing on insights from social science with the aim to develop a harmonized and operational methodology for S-LCA. A literature search carried out in 2015 in preparation of this keynote found 90 scientific publications on S-LCA in the open literature. Table 7 lists examples of case studies found for various applications (e.g., energy, waste, and agriculture). The literature also has a number of reviews of the field of S-LCA aiming to systematize, describe, and synthesize knowledge from S-LCA studies [50,144,167, 185,210,219,269].

Table 7 Case studies from the field of social LCA

Sector	Topic
Energy	Biofuels [32], Photovoltaic modules [245]
Agro-industry	Cut roses [53], Fertilizer application [179]
Electronics	Eco-labeled notebook [54], Laptop computer [75]
Building technology	Building materials selection [118]
Public services	Integrated water resource management and integrated packaging waste [165], Used cooking oil waste management [262], Informal recycling [249]

4.2 S-LCA methodology structure

Several methodological frameworks for S-LCA have been suggested in the literature [37,71,121,144,158,178,202,223,251]. The most commonly used framework is the one based on the guidelines from the UNEP/SETAC Life Cycle Initiative [251], which has been applied to assess a variety of economic activities since its publication in 2009 (including most of the cases in Table 7).

The quantitative S-LCA frameworks generally follows the fundamental structure of the ISO 14040 standard and includes the same decision analysis approach as environmental LCA:

- Problem definition (goal)
- Structure the problem and analyze objectives and main stakeholders (as part of scope definition)
- Score, sort, and rank alternatives (in the impact assessment).

Uncertainty and sensitivity aspects which are prescribed by ISO 14044 (2006) as elements of the interpretation within environmental LCA, are often not treated quantitatively in S-LCA although they are widely discussed in the literature as an inherent challenge. Sensitivity analysis may be used to identify the dominant links in the value chain and help to focus additional data collection efforts [71]. The following sub-sections outline the methodological state-of-the-art with respect to S-LCA.

4.3 Problem definition – ‘what’ and ‘why’?

Depending on the context and goal of the study, the object of the assessment (the ‘what’) can vary from a product/system (e.g., assessing concrete and steel [118]), to the organization level for general decision support (e.g., a social organizational LCA [178]), to an economic sector level (e.g., for tourism [9]). What is common in each assessment is the emphasis on considering social impacts across the life cycle of the object under study.

The reason to perform the S-LCA also varies and the differences in motivation relate to the applied (or inherently perceived) definition of the Area of Protection (AoP) of the S-LCA. An AoP describes the aspects that the company or assessor cares about and the scope of what they would like the LCA to reveal (in terms of the potential of the studied entity to affect change [109]). An Environmental LCA typically operates with an AoP that has three aspects: Human Health, Natural Environment, and Natural Resources [108]. While the first of these three is also relevant for S-LCA, it is evident that other aspects are inappropriate, and new AoP aspects are needed. Reitinger et al. (2011) found that ‘papers on SLCA show a broad consensus that the additional AoP (aspect) should be human well-being itself’ (echoing recommendations by [70,144,251,268]). However, the fuzziness of the concept ‘well-being’ leads to many more specific definitions in the S-LCA literature, which are context and culture dependent. S-LCA scholars perceive well-being independently or as an addition to existing LCA AoP aspects, e.g., as part of human health. It is further linked to several social groups: from the individual (subjective perceptions) to the society (intrinsic values) while some place it in a fuzzy area in between since individuals are part of and responsible for constructing societies. Table 8 lists example proposals found in the literature on how to define an AoP for S-LCA. It is to be noted, that the ambiguity in how to define the AoP propagates to all the subsequent steps in an S-LCA.

Table 8 Suggestion of how to define or approach an AoP for S-LCA

AoP definitions	**Ref.**
Add human well-being within human health	[268]
A description of the state of an individual’s life situation	[251]
Existence of physical, mental and social well-being of workers	[88]
Internal human resources, external population, macro-social performance and stakeholder participation	[37]
Human dignity and well-being, ‘representing the value of a good and decent life enjoying respect and social membership and with fulfillment of the basic needs’	[70]
Safety, quality of life, and equity for decision-making in an enterprise	[127]
Autonomy, well-being, freedom and fairness	[223]
Individual well-being is treated as a part of global population’s well-being	[74]
Social aspects involve human beings and the society in which they live including norms, rules, etc.	[244]
Include social performance of a government or other country-related entities	[76]
Individual well-being is related to a product system (individual AoP), and national well-being (societal AoP)	[142]
Societal AoP related to the capital approach: enhancing different types of social capitals (or social sustainability)	[199]

4.4 Problem structuring – 'for whom' and 'from whom'?

When the societal boundaries for an S-LCA are established ('for whom are the impacts assessed?'), the stakeholder groups for whom the impacts will be assessed must be selected, and this in turn depends on the problem definition (section 4.3). The Guidelines identifies stakeholders including society, local community, workers, value chain, and consumers as a suggested (not exhaustive) list of stakeholders when taking a company or product perspective. Macombe et al. (2013) reported that S-LCA has been applied at multiple assessment scales such as chains of companies, product chains; economic sectors, and even countries. In order to tackle the serious challenge of missing information by using generic data from statistical sources, higher-level sector/industry/country data have been frequently used. The SHDB and its related methodological approach [21,23] were designed particularly for high-level product category assessment and screening at the sector and country level, instead of for a particular product's value chain.

A separate issue is to identify 'from whom' the information will be secured to calculate the impacts and assess them. This relates to how 'stakeholder participation' is perceived and applied throughout the assessment. Typically, the commissioner of the study and the practitioner conducting the assessment define the problem and the objectives of the analysis as part of the goal definition of the S-LCA.

4.5 Objectives analysis

During scope definition, the objectives of the defined goal are analyzed to identify the extent of the study parameters, to define the assessment criteria and MMIs used to represent them in the study.

4.5.1 Impact categories – which social impacts to consider?

Following the environmental LCA approach, S-LCA criteria must be selected to describe the AoP (what characteristics describe 'wellbeing'?). These criteria may be organized into categories or sub-categories of impact, where each criterion seeks to measure an impact. An indicator can be found on different levels depending on the proximity of the impact to the AoP. To structure this situation, impact pathway thinking from environmental LCA may be applied. An indicator can refer to a mid-point in the causality chain, from action to AoP (where impact categories may include human rights, labor conditions, governance and transparency, social relations, and cultural aspects), or it may be located closer to an end-point (e.g., quality of life, human health, and security). The end-points collectively represent the AoP. Fig. 13 shows an example of an impact pathway for the Child Labor impact category that links incidences of child labor to their immediate impacts and resulting consequences with influence on the AoP that here is defined as 'Overall well-being.'

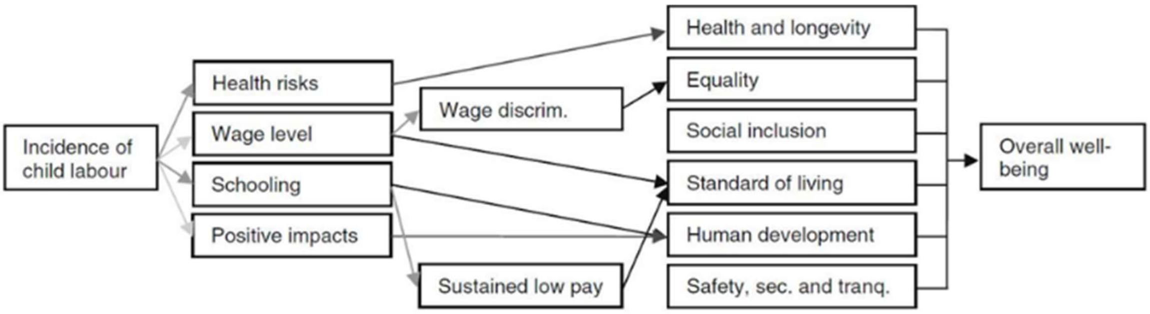

Fig. 13. Impact pathway for the impact category Child Labor [143].

Some authors even suggest criteria to accompany their AoP definition. For example, Reitinger (2011) and colleagues suggested eight impact categories to describe 'wellbeing,' i.e., life, knowledge and aesthetic experience, work and play, friendship, self-integration, self-expression, transcendence, and fairness [223]. Dreyer et al. (2006) note that the selection of relevant indicators for social impacts may be strongly case dependent, but also stress the need for a standardized set of indicators [70]. They suggest a combination of a set of mandatory indicators defined (based on international standards, e.g., the International Labour Organisation's (ILO) conventions of workers' rights based on the UN's universal declaration of human rights) with a set of more case- specific indicators that may be defined for the study. The issues that are assessed typically vary between different stakeholders across the value chain (workers in the upstream parts of the chain, consumers in the use stage, and the community in which a production facility resides). Table 9 shows social topics commonly found in social assessment initiatives.

The choice of which social impacts to include in the study reflects back to the problem definition and the stakeholder involvement in the assessment process. In addition, local or national norms and conditions drive which social impacts are relevant to consider in an S-LCA. As examples of specific impacts that may have different relevance depending on the context of the study, Dreyer et al. (2006) mention corruption and bribery, payment of income tax, illiteracy, and contribution to health care, e.g., in areas where HIV/AIDS causes substantial societal problems [70]. The highly local- or even site-specific nature of the assessments can also create ambiguities. The social impacts that are caused depend on the social entities involved, their cultural, ethical, and moral norms, perceptions and beliefs, and the company conduct. The latter is a function of inherent company characteristics like company culture and management practice and of the risks associated with the local culture and traditions as well as norms that may vary from sector to sector. Social impacts are often influenced by companies' behavior much more than by the technical nature of the processes themselves [70,242], and this makes analysis of local conditions highly relevant in the impact assessment of S-LCA, which constitutes one of the main challenges of the field [107]. To make such causalities stronger, sector specific social impacts may also be explored. Several researchers have also examined the relevant impacts for manufacturing and product development in a life cycle context [37,156,229].

Table 9 Frequency of social topics covered in comprehensive sources for social assessment (UNEP/SETAC, HDI, MDGs, OECD, GRI, UNGS, ISO 26000, ISEAL, COSA, WBSCD, IRIS, ETI, NEF, GSCP and others) [88]

Stakeholder group	Social topic considered	Frequency	Other topics referenced in the sources
Consumer	Health & safety	7/19	Transparency, Privacy, Feedback mechanism
Worker	Health & safety	13/19	Civil and political rights, Food security, Right to marry and protection of family, Remediation, Freedom of thought, opinion, expression, or religion, Inhumane treatment, Social dialogue, Right to work, Liberty and security, Well being
	Wages	10/19	
	Social benefits	10/19	
	Work hours	7/19	
	Child labor	10/19	
	Forced labor	9/19	
	Discrimination	13/19	
	Freedom of association	9/19	
	Training and education	7/19	
Community	Health & Safety	8/19	Access to intangible resources, Secure living conditions, Delocalization & migration, Cultural heritage, governance, indigenous rights, public policy, Promoting social responsibility, Respect of intellectual property rights, Corruption, Contribution to economic development, Fair competition, Prevention & mitigation of armed conflicts, Technology development
	Access to tangible resources	7/19	
	Community engagement	6/19	
	Local employment	4/19	

4.5.2 Indicators – what are the proxies that describe the impacts?

Separate from the choice of social impacts is the choice of MMIs to represent such impacts in a meaningful manner. Causal links between indicators and impacts can be direct (e.g., number of occupational accidents [118]) or indirect (e.g., percent unionized workers used as an indicator of freedom of association [119]). They can also be qualitative (e.g., 'job satisfaction') or quantitative or somewhere in between based on scoring systems [269]. Long discussions have been held about the appropriate choice of indicators for environmental LCA [109], but little attention has been given to the topic in the S-LCA community, although the representativeness of indicators is an issue that has been discussed among social theorists, e.g., the adequacy of GDP to meaningfully represent economic welfare [87]. The metrics- how to measure or model the social impacts?

Impact categories can be distinguished as Type I or Type II models according to the applied evaluation system [251]. In Type I, the indicators of the system are aggregated within a theme of interest and compared to a Performance Reference Point. The impacts are not measured in the form of 'unit per output', and thus lose the direct causal link to the object of the assessment (or the AoP). They further do not allow for immediate comparisons. In Type I models, the assessment uses aggregation formulas involving scoring and weighting systems to compile various types of indicators. As an example, 'Fair Salary' could be assessed through a binary indicator such as: '1' if 75% of the total workforce receives salary greater than the minimum wage, and '0' otherwise. This kind of data allows the identification of performance according to a 'relevant activity flow,' e.g., the percentage of a product system possessing different attributes [4,202]. In this case, the S-LCA results are representative of the product system's 'share' in terms of the activity variable. However, they focus on the behavior of companies in the value chain rather than the product system processes. Consequently, the quantitative link to the functional unit is lost and needs to be restored or created if required to meet the goal of the study. Wu et al. (2014) provide a thorough review of S-LCA studies applying a Type I approach using aggregation formulas involving scoring and weighting systems [269].

Type II models use impact pathways passing through a midpoint to an endpoint level implying quantitative causality throughout the assessment as illustrated in Fig. 13. Hunkeler (2006) translates the hours of labor required for each unit process into the capacity of the employees to access housing, health care, education, and necessities [121]. Weidema (2006) links quantitative inventory items, such as child labor, to damage categories, such as autonomy infringement and ultimately quantifies well-being in Quality Adjusted Life Years [268]. Wu et al. (2014) provide a review of S-LCA studies applying a Type II approach relying on quantitative modeling of impact pathways passing through a midpoint to an endpoint level [269].

Both assessment types have issues related to systematic identification of relevant stakeholders and accurate representation of real-world causal relationships [269]. A combination of the two is suggested by Parent et al. (2010) and Chhipi-Shrestha et al. (2014) via a combination of checklists, reference points, and alternative impact pathway approaches.

In environmental LCA, the inventory analysis compiles information about elementary flows of relevance to the environmental impact categories and their associated indicators as they are defined by the goal and scope of the study. The elementary flows are physical flows of substances and resources between the processes of the product system and the surroundings. In S-LCA, the focus is not on physical flows but on interactions that result in the social impacts included in the study. The inventory information that needs to be collected depends on the nature of the selected indicators, the location of impacts addressed within the system (see Fig. 13), and how the impacts are modeled. Sometimes indicator results are collected directly from the companies in the studied value chain. This may be the case for very site-specific Type I approaches [71], where the needed information about probability of incidences of child labor, forced labor, or discrimination at the company are collected from the companies. When more generic Type II approaches are used, the relevant inventory information could be the number of working hours together with a classification of the company according to its location and sector. This is the case for the SHDB that facilitates data collection for social impacts at a general level [22,23]. ‘Hotspots’ refer to production activities in the supply chain that may be at risk for social issues (Table 10). The database is made up of country and sector-specific indicator tables combined with a model to determine the countries and sectors with the highest share of working hours along the value chain of the product. To construct the database, over 400 publicly available data sources were reviewed, and over 200 of these sources were incorporated [23]. In the database, social topics are based on the guidelines from the UNEP/SETAC Life Cycle Initiative and have been compiled in Twenty Social Theme Tables.

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Table 10 Example of SHDB characterized social issues [23]

Category	Social themes	Data indicator	Characterized issue
Labor rights and decent work	Child labor	Child Labor % in country	Risk of Child Labor in country
		Child Labor % by sector	Risk of Child Labor by sector
	Wage assessment	Minimum Wages (USD) Average Unskilled Wages (USD) in country	Risk of Country Average Wage being < Minimum Wage
		NonPoverty Guideline (USD) Average Unskilled Wages (USD) in country	Risk of Country Average Wage being < NonPoverty Guideline

4.6 S-LCA challenges and outlook

The existing S-LCA methods still lack maturity and their practical implementation is challenged by lack of data that is sufficient, specific, and objective. The choice of assessment scale (unit process, company, industrial sector, country) is often not consistent with the goal of the study [171]. A firm scientific foundation and justification for the choice of social impacts has yet to be established [12]. Overall indicator appropriateness and representativeness is questionable. Regarding data collection 'desktop search' based on statistics found in literature, on company internal and publicly available reports, or in databases such as SHDB may lack the required site specific representativeness while site specific data collection (surveys, interviews, direct observations) requires time and is often not feasible in the lower tiers of the value chain. Apart from data availability, there are also difficulties accurately measuring and assessing qualitative data [219]. The allocation of impacts to the object of the assessment lacks standardization. The aggregation of impacts over the life cycle as the link to the product system is often less straightforward than in environmental LCA where it is based on physical flows associated with the functional unit. Such challenges are seen in several case studies [179]. Overall, the flexibility for subjective judgments in selection of social criteria, indicators, and assessment methods jeopardizes the meaningfulness of the results [144,167].

Environmental LCA quantifies emissions (of substances and wastes) and consumption of resources related to a defined product or system. It further employs natural sciences to describe causal links between these emissions and their contributions to various environmental impact categories. The causality between emissions and impacts, the relative accuracy in allocating them to specific actions across the life cycle makes quantitative methods adequate for building that methodology. Environmental LCA is methodologically challenged when it comes to trade-offs between environmental impacts. This is reflected in the debated normalization and weighting methods [135,162]. This lack of consensus showcases the difficulty in rationalizing and quantifying circumstantial results in environmental LCA, a difficulty that is heavily amplified in S-LCA since social sustainability is much more about value weighting by analysts. Using quantitative approaches for assessing social impacts thus inevitably entails strong ambiguities, and attempts to harmonize or standardize these have so far not been successful.

S-LCA attempts to encompass all social entities that are part of, or are affected by value chains. Who is the decision-maker that will define the problem (social sustainability) and the criteria (such as social topics and indicators) that need to be satisfied? Is it the companies, the consumers, all related actors, globally agreed social norms, etc.? Decision-makers (individuals or social units) can all relate differently (rationally or inexplicitly) to the problem and the criteria. How can different cultures, values, ethics and working norms be appropriately represented? Multinational companies operate in a dynamic and volatile global environment both in terms of supply chain and market. In such a context, an indicator-based approach assuming that different context-dependent social units can be deconstructed and subjected to measurable requirements, is challenged by social theory.

After a decade of S-LCA methodology research, it is not clear to what extent future developments will mirror environmental LCA with international standardization and scientific consensus building around central elements of the methodology and modeling of individual categories of impact. The different scientific foundations of environmental and social LCA mean that they face very different challenges as emphasized above, but it seems clear that life cycle approaches to assessment and management of social impacts from products, companies, and value chains will continue in the future.

5. Integrating social, environmental, and economic considerations

The manufacturing of consumer goods and industrial products has contributed significantly to economic prosperity around the world. From the previous sections, it is clear that addressing social considerations within the manufacturing enterprise is not an easy challenge. As has been seen, approaches are often subjective and impose substantial challenges in terms of collecting data, selecting impact categories/stakeholder groups, etc. Moreover, an overarching consensus has yet to be reached on indicators, methods, and a host of other issues. Nevertheless, the social dimension of sustainability is a topic of growing importance, and companies need to address the impacts within their supply chains.

This section provides some examples of how companies have integrated the social dimension with the economic and/or environmental dimensions of sustainability in varying degrees of detail. The first two sections focus on different integration approaches that have been employed at the micro (company) level and the macro (economy) level. The third section looks at the implementation of these approaches in daily operational practice.

5.1 Addressing multiple sustainability dimensions

Efforts related to sustainability by global manufacturers have advanced rapidly over the past few decades [101]. As manufacturers endeavor to achieve the goal of sustainability, they often attempt to simultaneously address the three dimensions of sustainability: economy, environment, and society. This section describes decision-support activities to consider all three of these dimensions through total cost of ownership (TCO), triple bottom line (TBL), and life cycle sustainability assessment (LCSA) approaches.

5.1.1 Total cost of ownership

The outcome of a decision-making process can vary depending on the perspective of the decision-maker, e.g., whether they have a short-term (motivated by yearly bonuses, short-term incentives, etc.) or long-term (family-owned business for example) perspective. Regardless of perspective, cost and profit remain important drivers for decisions. A practical approach that combines and categorizes different cost aspects is the TCO approach. The elements that make up the TCO are depicted in Fig. 14.

The TCO approach serves as a decision-support method for global manufacturing companies to generate make-or-buy decisions (including in-house, outsourcing, and offshoring) or to decide among potential suppliers [36]. Costs can be categorized into i) transport and logistics costs, ii) transaction costs, iii) depreciation, amortization, and capital costs, and iv) risk costs. While most of the criteria within the TCO analysis are cost elements (variable costs, fixed costs, and risk costs), the method may also include nonfinancial assessment criteria (e.g., delivery lead time, product quality, personnel costs, macroeconomic cost criteria, and qualitative criteria) [232].

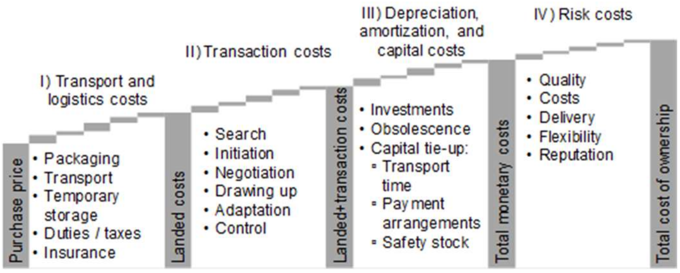

Fig. 14. Elements that make up the Total Cost of Ownership [232]

TCO was developed with an emphasis on its practical usability. Even though it mainly focuses on the economic perspective, the TCO approach already includes triple-bottom-line thinking to some extent: social (and environmental) indicators can be considered within the risk category of 'reputation' that is a nonfinancial category, and used as a tie-breaker in the decision process. This can make the difference whether one alternative is favored over another. The scenarios that are compared might, for example, be 'make,' 'buy local,' or 'buy offshore.'

A limitation of TCO is that the desire to include environmental and social aspects in the process may be undermined by a short-sighted decision-maker. As long as the alternatives satisfy the legally required social and environmental boundaries, social and environmental perspectives are only addressed as part of the 'risk of a damaged reputation,' and therefore only considered if they could negatively influence the economic perspective. An advantage of TCO is that it may be extended with additional cost categories in order to better reflect specific social and environmental indicators if any are deemed important. Fig. 15 shows the results of a survey of 178 Swiss companies conducted in 2010, mainly from the machinery, electrical, and metal industries. It depicts the importance of different TCO elements. Respondents were able to select weightings ranging from 1 (minimum) to 6 (maximum).

Fig. 15 shows (at least at the time of the survey) that risk of damaged reputation (lowest line in the figure) is only of average importance compared to the other cost elements. Risk of damaged reputation may be a higher priority in today's market environment due to growing consumer awareness.

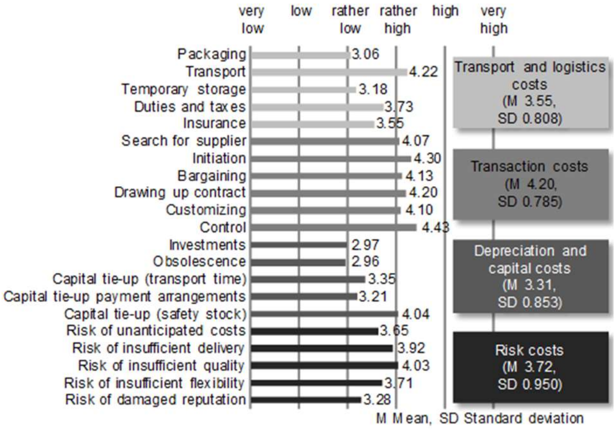

Fig. 15. Importance of the elements of the TCO [36,232]

5.1.2 Triple bottom line

Awareness around sustainable consumption is increasing; one notable example is Lifestyles of Health and Sustainability (LOHAS) [29]. It took many years for the 'first economic pressures imposed by the environmental movement in the early 1960s' to produce the kinds of changes we now see in sustainability thinking that embrace environment, society, and economy [234]. This change in mindset, represents an extension to the previously introduced financial (TCO) perspective, and can be described as triple bottom line (TBL) thinking (or the three Ps: people. planet, and prosperity). BASF has developed a TBL tool for Socio-Eco-Efficiency Analysis (SEEbalance) in cooperation with various academic research institutions in order to incorporate social aspects of sustainability 'into BASF's existing eco-efficiency analysis' [231]. For this, environmental LCA indicators and economic TCO indicators are extended by adding social indicators grouped by stakeholders that BASF identified as relevant: employees, local community, future generations, consumers, and national/international stakeholders [16]. Examples of these indicators are shown in Table 11.

Table 11 Social indicators for stakeholder categories (BASF SEEbalance model [16]).

Working conditions	**Int'l community**	**Future generation**	**Consumer**	**Local and national community**
Working accidents	Child labor	Number of trainees	Toxicity potential	Employees
Fatal working accidents	Foreign direct investment	R&D company expenditure	Other risks + functional product chars.	Qualified workers
Occupational diseases	Imports from developing countries	Capital investments		Gender equality
Toxicity potential + transport		Social security		Integration of people with disabilities
Wages and salaries				Part time workers
Professional training				Family support
Strikes and lockouts				

The SEEbalance model considers all sustainability dimensions and may be used to evaluate different product and process alternatives. It has been reported that challenges during development included the complexity of social issues, assessment methods, aggregation procedures, limited availability of data, and lack of acceptance of the model by various groups [231].

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Another approach that seeks to address the TBL is full cost accounting. In a review of 4381 papers, ten full cost accounting methods with a diverse level of development and consistency were identified [136]. The full cost accounting approach has been applied in different industries such as energy, oil and gas, chemical, urban development, and the automotive industry. Another example comes from KPMG, a professional service company and leading corporate auditor [155]. The KPMG methodology endeavors to integrate societal value and corporate value and not only 'measure and manage the value a company creates for society,' but also 'understand what that means for its future profit potential' [155]. The underlying philosophy is that the core nature of investment and return should not be a tradeoff 'between social and financial interest, but rather the pursuit of an embedded value proposition composed of both.' This suggests that it is important to find frameworks and tools 'to track performance of a Blended Value Proposition' [78].

Fig. 16 shows the application of KPMG's methodology for integrating measurement of the social and the environmental dimensions of sustainability to LafargeHolcim [116]. The IPL (integrated profit and loss) statement was reported in 2014 for the first time, in an effort to quantitatively measure the TBL [116]. Fig. 16 shows the different indicators that have an impact on the triple bottom line, but each category (Financial, Socio-economic, and Environmental) is dominated by a single measure.

While it is clear that many indicators of the social and environmental dimensions of sustainability are quantitatively lacking, the TBL-IPL approach does allow a company to evaluate its sustainability goals. The IPL provides a consistent way to measure its progress over time. In addition, the tool can be used 'to identify where 1 US dollar invested would bring the highest societal return' [116].

Like other approaches, full cost accounting may be misused by companies to 'greenwash' or 'bluewash' (when a company advertises its commitment to social responsibility for public relation benefits) their activities and may only appear in yearly reports if the TBL result is positive. Nevertheless, it also represents an approach to holistically measure the impact of a company and provides a quantitative evaluation upon which improvement opportunities may be based.

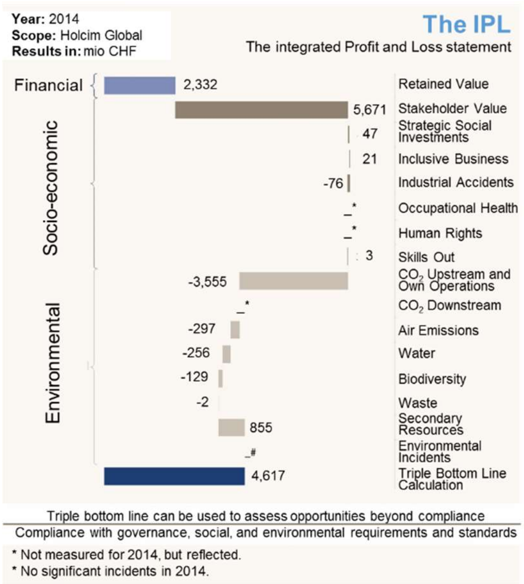

Fig. 16. The IPL - Integrated profit and loss statement (according to [116]).

5.1 3 Life cycle sustainability assessment

A number of approaches have been employed to combine the results of life cycle assessments (in the economic, environmental, and social dimensions) or consider these multiple dimensions as part of an LCA evaluation. Many have referred to such approaches as life cycle sustainability assessment (LCSA). Based on the foregoing comments of this paper, it is clear that many challenges exist with respect to LCSA including indicator selection and weighting issues. In addition to these issues, from a practitioner standpoint, Finkbeiner et al. (2010) note that applicability is a concern due to the limited development of robust methods for measurement and lacking visualization tools to present results [85,246].

Clarke-Sather et al. (2011) analyzed a small/medium enterprise that examined sustainability indicators using two different approaches [55]. A main challenge was the ‘inability to measure quantitative indicators or knowing how to improve sustainability after measuring it’ [55]. It was concluded that an outside expert is likely needed to set up workable sustainability measurement systems. Even experienced experts are challenged to establish workable, widely applicable systems. Rametsteiner et al. (2011) described how the EU has funded large research projects aimed at developing design tools for sustainability assessments [218]. These efforts have led to sector-specific tools that are difficult to extend to new applications [218].

This paper has presented a number of acronyms relating to LCA across the three dimensions of sustainability and described the principles and methods associated with each tool. These tools include life cycle costing (LCC or f-LCC – financial life cycle costing), S-LCA, E-LCC (environmental life cycle costing), and E-LCA (environmental life cycle assessment). The links between the different tools are depicted in Fig. 17 [152]. In the figure, solid arrows indicate the flow of information and dashed arrows are associated with supplemental information that may be useful, but are not required [117]. The indicated tools are not synchronized; for example f-LCC only considers costs of one actor at a time, and external costs are omitted, e.g., environmental costs. E-LCC on the other hand considers the entire product life cycle, which includes many actors [117,152]. While f-LCC does consider some environmental costs, e.g., waste disposal costs, for some tools (e.g., E-LCA), there is no conversion from environmental metrics into monetary measures [117]. This conversion is achieved with full environmental LCC (fE-LCC), where E-LCC is extended using ‘monetized, noninternalized environmental costs’ [117].

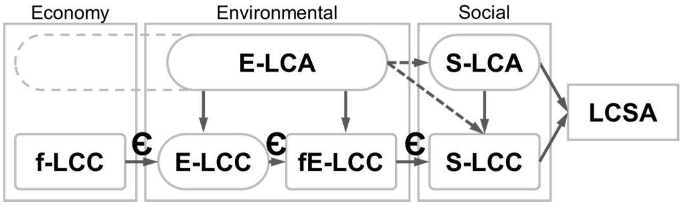

Fig. 17. Interaction between different sustainability assessment tools (adapted from [117]), without cost benefit analysis (CBA).

Kloepffer introduced the LCSA approach in 2002 [52]. To include LCC and S-LCA in the sustainability assessment of products, two options were proposed [152]:

Option 1: LCSA = E-LCA + LCC + S-LCA or **Option 2**: LCSA = 'LCA new'
(where LCC and S-LCA serve as additional impact categories in Life Cycle Impact Assessment – LCIA)

The difference is that while option 1 performs three separate life cycle assessments, there is only one life cycle inventory (LCI) model that is needed for option 2 (three inventories are needed for option 1). This view was challenged by de Haes (2008) who argued that not all impacts should be squeezed into an E-LCA and that for S-LCA this challenge is even more difficult [152]. The 'aggregation and weighting of different environmental and social impact categories in order to compare different products are controversial' [117]. As has been noted, establishing a societal inventory similar to that for an environmental or economic LCA is especially difficult since consensus has not been reached on the indicators [121].

5.2 Integration using national level indicators

Social issues are inherently connected to environmental and economic activities. Assessment methods and modeling techniques that integrate multiple dimensions of sustainability provide tremendous insight into the interconnectedness of systems. Input-output models (IOMs) provide one method by which economic activities can be connected to social impacts [126,127,202]. IOMs allocate levels of impact to a specific product, process, sector, or group (e.g., carbon emissions per capita). A key step in constructing IOMs is determining potential drivers (causal variables) for social performance (footprint). For example, drivers influencing the social footprint of a manufacturing process could include capital and labor inputs, growth rate of the economy, technology changes, demand for products and services, and population demographics (e.g., affluence) [112]. IOMs are used to identify major impact sources, benchmark the performance of sectors, and track impacts over time [190].

IOMs have been successful in the environmental sector through the development of the Economic Input-Output Life Cycle Assessment (EIOLCA) model [111]. EIOLCA assumes environmental outcomes as proportional to economic activity. Though average values are used, the method provides an order-of-magnitude estimation of environmental effects caused by business operations. EIOLCA accounts for all economic activity (including inter- and intra- business sector monetary flows) across the supply chain for a particular manufactured product [184]. EIOLCA employs public databases that describe economic supply and demand across hundreds of economic sectors and subsequently uses an emission factor to scale environmental impacts. A challenge for using IOMs in the social sector is how to weight and assign social impact factors, especially acknowledging the varying needs of stakeholder groups as discussed in Section 3. The development of a consistent method of accounting for impacts can enable better assessment of the differences between various products, processes, and sectors in terms of social impact.

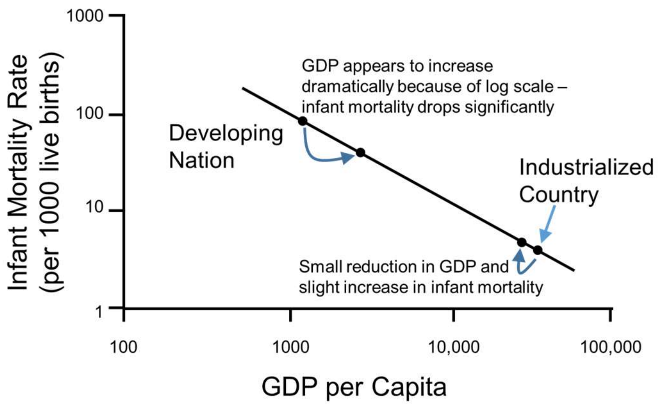

Fig. 18. Effect of outsourcing from industrialized to developing nation [126].

To illustrate how an IOM may be used to assess the effect of a policy change, consider the infant mortality data (for various nations) previously shown in Fig. 3 [126]. This data was related to GDP in the log-log space via a linear model [126]. Using this linear relationship, a change in supplier from an industrialized nation to developing nation was considered (Fig. 18). As is evident, although the predicted impacts are modest, such a change has a slightly negative effect on the GDP and infant mortality for the industrialized country, but a strong positive effect on the GDP and infant mortality for the developing nation – overall, there is a net benefit in terms of infant mortality. Of course such change in suppliers has its own set of broader ethical and policy implications.

The IPAT equation provides another example of tying economic activity to impacts (Equation 1).

$$\begin{aligned} I &= P \cdot A \cdot T \\ Impact &= Population \cdot Affluence \cdot Technology \end{aligned} \qquad (1)$$

Within the IPAT equation, P is the number of people, A is the GDP per capita, and T is impact (resources consumed, illiteracy, waste produced, etc.) per monetary unit. The IPAT equation was developed in the hopes of creating a simple model that connects aspects of diverse systems namely, technology, economics, environmental, and social systems [49]. It relates indicators to economic activity through the affluence term. Small changes in GDP per person (realized through manufacturing) can lead to dramatic impacts in developing countries, whereas industrialized countries see smaller gains and losses. Speaking about the final term in the equation, it has been noted that technology offers the greatest opportunity for realizing a sustainable society [2]. It is through engineering innovation where intervention may occur to simultaneously meet the needs of society, present and future, and reduce impact.

5.3 Globalization – a special case of integration

The term 'globalization' refers to how manufacturers spread their activities across the world: marketing products globally, creating new manufacturing facilities in various nations, having a global product development process, outsourcing production to disparate supply chain partners, to identify a few. Globalization is a complicated phenomenon that affects all three pillars of sustainability. For this paper, attention will largely be devoted to the social sustainability effects of site location strategies. Such strategies are motivated by the following factors [232]:

- Some market segments require (due to treaties and/or regulations) the local presence of production and distribution facilities in order to sell into that market, or because of customer demand.
- The time factor in development, order processing, and service in some markets may require decentralized handling of products at a local level.
- Cost pressures due to the market or focus on core competencies and core businesses may cause value added activities to be moved to locations with specific know-how or lower costs.

The first two factors do not simply support local outsourcing; rather, they demand offshoring of design/production/support to the area where the customers are based. In such cases, the customers are integral to the remote location in question, and the workers and community associated with the manufacturing location are also key stakeholders. The social dimension of sustainability is especially important in these situations.

For companies that currently manufacture in high-wage earning countries, the third strategy often means offshoring production to low-wage countries. The social dimension of sustainability then becomes an acutely important consideration, owing to a variety of potential problems and benefits. Given the dynamics of the global market and the complexity of global production, some manufacturing enterprises are considering ‘reshoring’ (moving offshore production back to its original location). This necessitates some discussion of the societal issues (causes and consequences) related to reshoring.

5.3.1 Effect of offshoring from industrialized to developing nations

The reasons for a company to revise its location strategies noted above are primarily economic in nature. Location decisions may center on centralized versus decentralized production or production in country X versus country Y [146,193,195]. Fig. 19 shows some of the location options as a function of two dimensions, for an example product with four principal operations and subsequent distribution.

As is evident, Fig. 19 shows how various issues drive location/centralization decisions [235]. Generally, a strategic redesign of the production network is part of an integrated (re-)design that also includes the distribution, service, and transport network [233]. Offshoring can occur for financial reasons or because of regulations/treaties relating to local production for market access. In addition to labor costs, other costs include taxes, energy costs, and overhead costs (particularly for R&D). Communities have an interest in manufacturing companies being located in their area, owing to the potential for job creation and income for local citizens. As with the interests of other stakeholders, the interests of society itself may vary [52]. Other benefits that have been reported for a new manufacturing site include ‘social peace’, political stabilization, local supplier contracts, and indirect improvements (e.g., improved healthcare and enhanced education infrastructure). Cooperation between a company and local economic development organizations can produce mutual benefits.

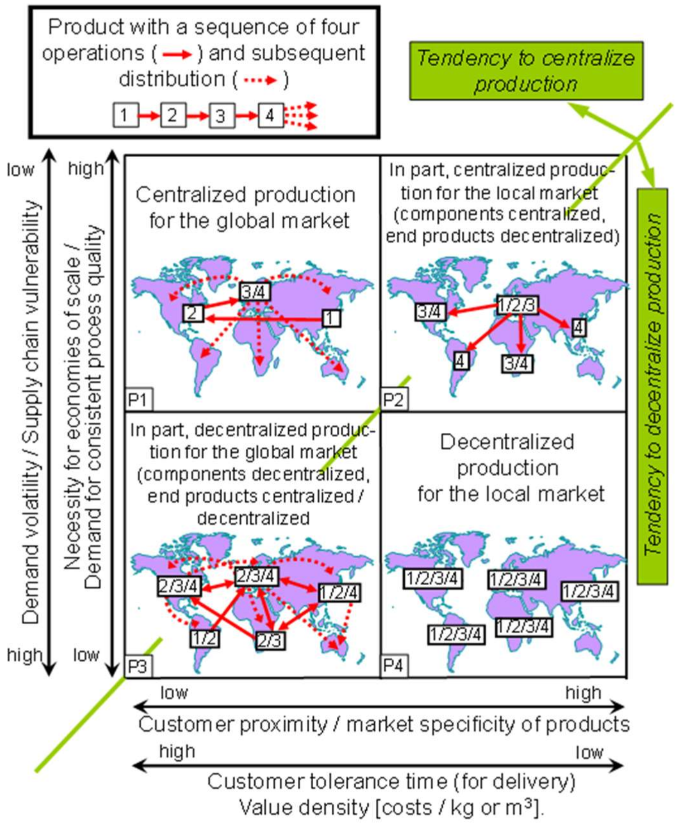

Fig. 19. Location concepts for production, (adapted from [235]).

Local communities often give substantial tax breaks to a manufacturer to secure a commitment for a new facility in order to derive the benefits noted above. In fact, some localities have offered substantial subsidies in order to attract large companies to their area. When Volkswagen was considering a Tennessee, USA site [265], the local community made available 1400 acres (5.67 km^2) of land and infrastructure. In return, Volkswagen made investments of over $1 billion, created employment for more than 3,200 people, and had more than 9,500 indirect jobs created. The economic effect on the local community was an expected $12 billion in income growth and $1.4 billion in tax revenues. Volkswagen considered the societal benefits to be part of its TBL.

5.3.2 Socially sustainable offshoring

Of those companies deciding to offshore production, an increasing number are reviewing their social sustainability performance in the offshore site. This is often accomplished by defining and implementing a 'code of conduct' (CoC), and for suppliers, a 'supplier code of conduct' (SCoC). Designing a CoC involves setting normative levels towards sustainability dimensions. A CoC likely includes rules for areas such as labor standards, health and safety, environment, ethics, and compliance. As part of a CoC, responsibilities should be developed so that the risk/return ratio is well balanced. Otherwise, it might prove difficult to recruit suitably qualified senior managers for challenging leadership positions.

Companies in the electronics industry were surveyed in 2007 on matters typically associated with a SCoC [205]. At the time of the survey, a SCoC was not generally required of companies in the sector, whereas it was commonly used in retail or the textile industry sectors (for example, in relation to child labor). Only 24 of the 75 electronics industry companies surveyed (or 32%) had a SCoC. Table 12 shows the percentage of these 24 companies that addressed specific issues of the SCoC or concerns relating to labor practices. A list of the other areas has been reported [232]; insight is also provided into the considerable effort needed to be socially sustainable when offshoring.

Table 12 Issues addressed by SCoC within electronics industry and their frequency of occurrence (excerpted from [205]).

No.	SCoC Element and frequency of occurrence (n=24)	
1	***Labor Standards***	
1.01	Forced labor	83%
1.02	Child labor	88%
1.03	Juvenile workers	33%
1.04	Non-discrimination	79%
1.05	Harassment, inhumane treatment	50%
1.06	Respect and dignity	42%
1.07	Freedom of association	50%
1.08	Working hours, rest periods and breaks	54%
1.09	Minimum wages and benefits	42%
1.10	Overtime compensation	25%
1.11	Recorded terms of employment	17%
1.12	Employee privacy	8%

Energy-intensive industry sectors, such as chemicals and petrochemical, iron and steel, cement, and pulp and paper, were some of the first to consider sustainability. They were early adopters, as opposed to conventional manufacturing industries, owing to the potential negative environmental impacts (e.g., airborne emissions) of energy intensive facilities on local communities. This was also applied to their offshore subsidiaries.

LafargeHolcim is one such energy intensive company. They have adopted a CoC that includes three topics: i) integrity in the workplace (including occupational health and safety (OH&S), diversity, fairness and respect), ii) integrity in business practices (including anti-bribery and anti-corruption, fair competition, conflicts of interest, insider trading, gifts and hospitality), and iii) integrity in the community (environment, human rights, community engagement) [115,157]. LafargeHolcim advertises a ‘100% compliance policy’ with respect to their code of conduct, and local implementation is part of their global training program. They are also implementing a Sustainable Development Ambition 2030 report that seeks to support socially sustainable offshoring [114]. The TBL is integral to their strategy that focuses on three areas: climate, resources and communities (Fig. 20). It is evident that LafargeHolcim views manufacturing as a vehicle to provide benefits to all stakeholders; the 100% compliance policy even applies to countries with high levels of bribery and corruption. This commitment is founded in the belief that in the long term, such a practice will provide TBL benefits to the corporation, and social benefits to local communities (e.g., create more jobs).

5.3.3 Effects of reshoring

Due to the changing global situation, the economic motivation for a company to offshore its production is subject to constant change. Fig. 21 shows the dynamics of the problem as revealed by a survey of medium-sized companies in the mechanical and electrical industry (M&E) in Germany from 1999 to 2012[148] (in addition to work by the Fraunhofer ISI in Karlsruhe, Germany). The survey investigated reasons for companies to offshore and reshore production activities. For companies that reshore their activities during a given year, the figure indicates the percentage of companies specifying a given reason for reshoring. The two dominant reasons) and flexibility (mainly problems with the delivery time). The inversion of the relative importance of these two main reasons in 2009 is explained by the economic downturn in 2008/2009. The economic downturn reduced delivery problems (for example, full port facilities were not a problem), but led to a substantial increase in quality problems (for example, due to a shortage of expertise and experience as staff were laid off).

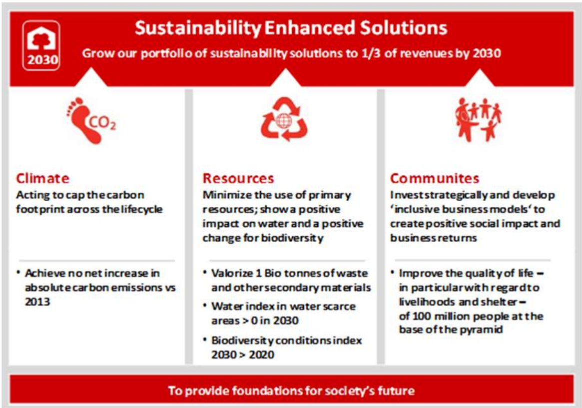

Fig. 20. LafargeHolcim's sustainable development ambition (according to [114]).

The statistics shown in Fig. 21 demonstrate the importance of strategic location planning. Location planning is a critical and complex task, and mistakes (or reversals) can become very costly [82]. There is a risk with outsourcing that process knowledge or the ability to successfully carry out certain activities may be lost [259]. In many cases, the know-how at the original location is lost when activities are transferred to the new location; in hindsight, efforts may have been better invested in training a new generation at the original location. Following an offshoring move, workers at the original location may separate from the company, and will no longer be available to rebuild expertise if reshoring occurs. Another factor to consider is that the company's reputation at its original location may suffer due to offshoring. Even when a company seeks to develop a new center of expertise at the original location, workers may not believe in the company's long-term commitment to the project.

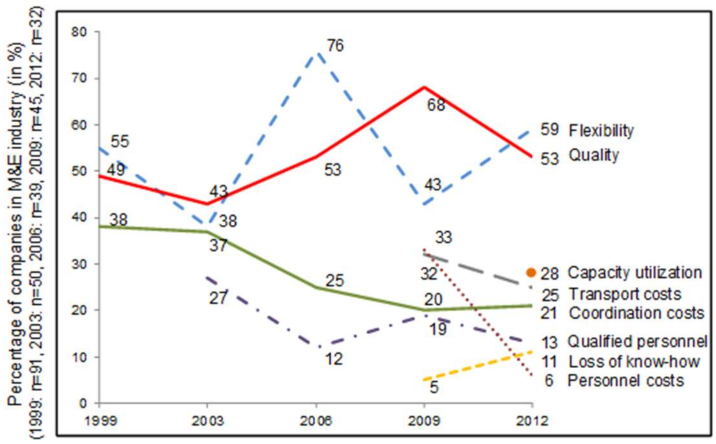

Fig. 21. Reasons for reshoring (adapted from [232]), with data from [148]).

What are the consequences for a local community when a company that had offshored to that community, decides to reshore to its original location? Two trends have been reported. Sometimes, reshoring has had no negative consequences for the local community. This was the case for a specific instance in China [206]; Chinese suppliers that had experienced substantial growth [148], without actively wishing this to happen, had no concerns returning to their original state.

On the other hand, the social consequences in countries with a declining industrial sector may be much greater [169]. Several automakers intend to stop producing cars in Australia by 2017. Local workers for the automakers will lose jobs, and local suppliers will lose customers, which will have major employment and local R&D consequences. Moreover, such a planned reshoring is expected to have concomitant negative effects on other social performance MMIs.

5.4 Summary

With a globally connected network of suppliers, producers, and consumers, a comprehensive sustainability solution has yet to be developed. Some companies have embraced the goal of sustainability integration by including various tools from TCO, TBL, LCSA, and IO modeling. While employing such tools remains challenging with regards to social impacts, the combination of these tools can increase awareness and influence reporting on company actions. A clear limitation to the effectiveness of these tools is the lack of empirical data linking social impacts to manufacturing actions. Offshoring, outsourcing, and reshoring present the collective anomaly to the above-mentioned limitation by creating measurable impacts for stakeholders both local and abroad.

6. Conclusions and recommendations

We have explored the social pillar of sustainability, and examined the state of knowledge on how manufacturing affects society. Four broad categories of topics have been investigated: i) social indicators and frameworks, ii) effect of manufacturing on social performance, iii) Social – Life Cycle Assessment methodology, and iv) integration of social, environmental, and economic considerations. Key conclusions and directions for continuing research are summarized in the following sub-sections.

6.1 Summation Points

The following major points are presented in the paper:

- Social indicators and frameworks
  - Of the three dimensions of sustainability: economy, environment, and social, the least is known about social;
  - Challenges exist to internalize and operationalize social sustainability, especially in the manufacturing domain;

- Effect of manufacturing on social performance
  - Social impacts vary significantly as a function of stakeholder group;
  - Stakeholders have varying needs with no consensus on representative indicators for each group;
  - Understanding of multiple disciplines is necessary to accurately measure and evaluate social impacts.
- Social life cycle assessment (S-LCA) methodology
  - Company influence propagates through its value chain and so should responsibility;
  - Social sustainability should employ a life cycle perspective;
  - The methodology for S-LCA is still immature, including which impacts to include and how to model them;
  - Social decisions about suppliers requires site specific information.
- Integrating social, environmental, and economic considerations
  - Manufacturing facilities impact much more than their local communities;
  - Approaches to address all three pillars of sustainability include the TCO, TBL, LCSA, and IO methodologies;
  - There is a dearth of social data and a lack of standardized approaches for considering different sustainability dimensions;

6.2 Future directions for research

Promising directions for continuing research related to how manufacturing influences the social pillar of sustainability include:

- Social indicators and frameworks
  - Identifying indicators throughout the upstream and downstream supply chains to account for social consequences of a company's activities;
  - Establishing an association between social performance and financial performance based on indicators;
- Effect of manufacturing on social performance
  - Clarifying indicators for stakeholders based on needs levels, leading to predictive assessment tools for social impacts;
  - Clearly and quantitatively defining and understanding the scope and boundary of social impact assessment;
- Social life cycle assessment (S-LCA) methodology
  - Developing a consensus about S LCA indicators;
  - Understanding of how social inventory is linked to indicators and impacts by establishing causal relationships;
  - Standardizing central elements of social LCA methodology.
- Integrating social, environmental, and economic considerations
  - Establishing standard data on economy, environment, and society for use in comparing among companies and countries;
  - Developing a standardized and widely accepted approach to consider multiple dimensions of sustainability;

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- Improving knowledge about the social consequences of offshoring and reshoring (both at the original and new locations).

The authors expect that the next decade will see tremendous advancements in our understanding of how manufacturing influences the social pillar of sustainability. Key challenges are developing a consensus of standard data, and establishing methods that can be employed for decision support.

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